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COMPARATIVE EVALUATION OF HOT WATER AND STEAM DISTRIBUTION SYSTEMS FOR DISTRICT HEATING

SUMMARY REPORT

PREPARED FOR:

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A Comparative Evaluation of Hot Water and Steam Distribution Systems for District Heating

1.0 Introduction

1.1 Project Objective

This study was conducted to assist those who are involved in the operation, assessment and investment decisions related to existing and new DH systems in Canada. Based on the statement of work established for the study, the project objective was:

> To describe the alternative steam/and hot water distribution technologies and to develop a comparative amaylysis for the two systems.

Since few Canadian engineers and district heating system operators have direct experience with hot water distribution technology, the study should also contribute to a balanced and comprehensive assessment of the options.

The comparison of steam and medium temperature distribution technologies was carried out in three phases:

1) The design principles associated with each were developed and compared;

2) Preliminary steam and hot water distribution designs were prepared and then compared for two case study sites: replacement of an existing system and a new system;

3) Overall conclusions were reached as to the comparative advantages and limitations of steam and hot water systems for typical Canadian applications.

1.2 Study Methodology

The study involved six steps:

1) The principal distribution alternatives used for district heating (and their common variations) were described.

2) The principles and parameters associated with the design of steam and hot water distribution systems were discussed and evaluated in the context of the technical, economic and organizational environment in Canada.

3) Preliminary designs of the most representative steam and hot water technologies were prepared for one new DH project and one replacement assessment of an existing system.

4) The principles and parameters discussed in step two were then applied to illustrate the relative advantages and disadvantages of steam and hot water for the projects under consideration.

5) Documentation of the work carried out was prepared for presentation in the final report.

1.3 Study Team

This study was managed by IEA Consulting Group Ltd., a firm with extensive experience in directing assessments of energy management technologies in general and district heating projects in particular. The technical and economic analysis in the study were directed by AFE Engineering Inc. (AFE), the Canadian subsidiary of one of Sweden's leading consulting engineering firms. AFE was assisted by Maunder and Britnell Engineering Ltd., a consulting engineering firm with significant experience related to Canadian district heating systems.

2.0 Comparison of Design Principles of Steam and Hot Water Distribution Systems

Section 2 of the main report presents a comparison of design principles for steam and hot water distribution systems. The comparison of principles deals with seven major aspects of distribution system design:

1) Basic System Alternatives

2) User Requirements

3) Connections to Users

4) Distribution System Configuration and Parameters

5) Production Plants

6) Maintenance and Operation

7) Availability of Technology

The major differences are discussed in the report with a detailed discussion included as an Appendix.

3.0 Case Studies

3.1 Introduction to Case Studies

Two district heating systems were selected for case study analysis to compare steam and hot water technologies. The first case study was based on a prospective new district heating system in downtown Charlottetown, Prince Edward Island. Such a system would have approximately 40 subscribers and a total connected load of 12 MW. The second case study was based on the existing steam distribution system at McMaster University in Hamilton, Ontario. At the time of this study, the McMaster system connected 33 campus buildings and a hospital, and had a total load of approximately 33 MW.

3.2 Charlottetown

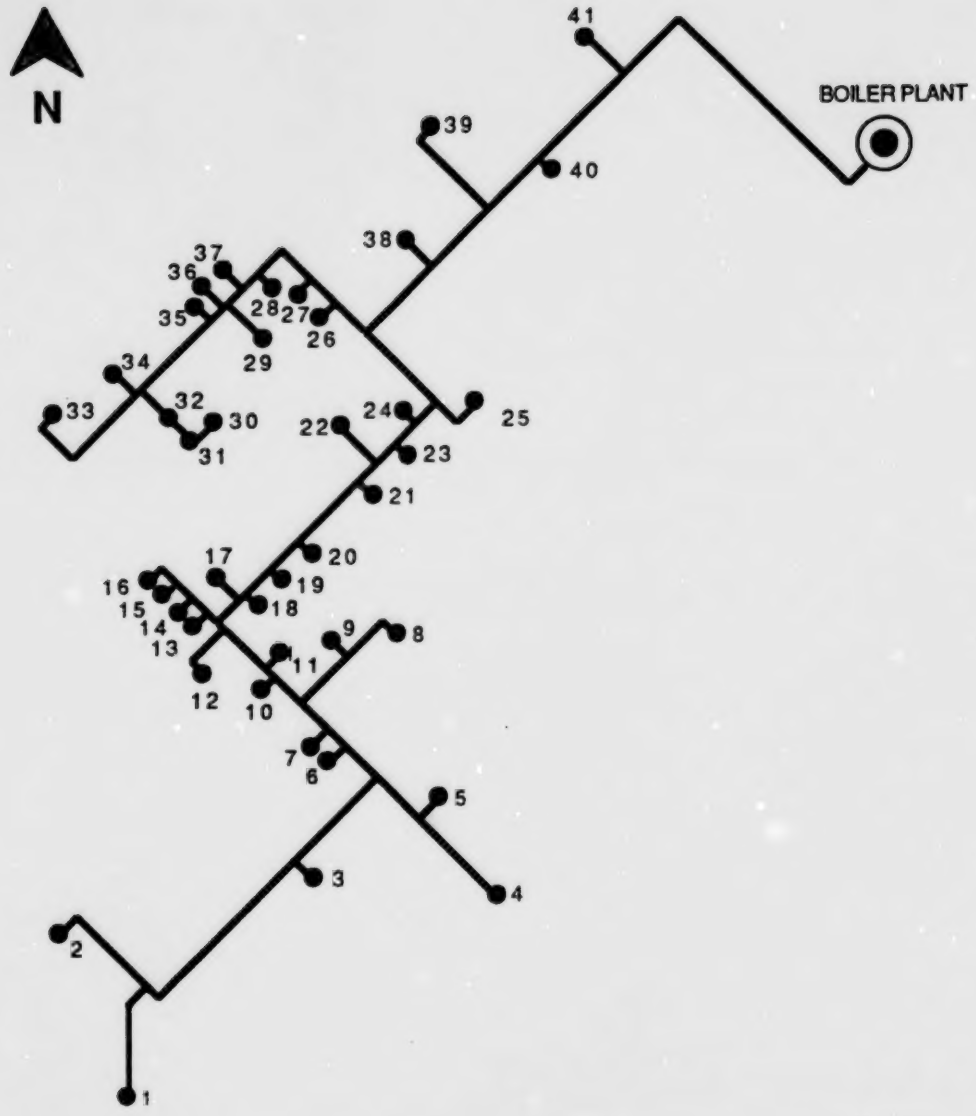
3.2.1. Description of Site

Two district heating projects had been developed in Charlottetown, P.E.I. However, neither project incorporated the downtown core. This case study evaluated a distribution system for one of the options being considered for DH development in the downtown area.

The approximate layout for the prospective system is given in Figure 3.1. The proposed system would include 41 customers with individual peak demands of approximately 50-200 Kw and a total connected load of approximately 12 MW. Four of the subscribers were heated by low pressure steam systems. Two of these could be completely converted to hot water and the other two (sites 2 and 39) substantially converted to hot water. Sites 2 and 39 used process steam, one for a kitchen and laundry and the other for laundry only. Conversion costs for the four sites ranged from $10,000 to $100,000. All steam use that could be converted was low pressure steam and none of the sites had absorption chillers. The remaining steam use was at approximately 2-7 bar g (30-100 psig) and could not be supplied by the DH system.

The new boiler plant that would supply the energy was assumed to be located adjacent to an existing 30 MW oil-fired standby generating station.

Figure 3.1



Charlottetown
District Heating System
Layout and Subscribers

3.2.2 Comparison of Steam and Hot Water Distribution

A summary of the comparison between the two preliminary designs for a new downtown Charlottetown system is presented in Table 3.1. Each portion of this comparison is discussed below.

System Configuration

The distribution network was 3,866m in length, with 41 sites connected to the system. The peak load was approximately 12 MW. Annual delivered energy was estimated at 25,000 MWh.

User Requirements

The steam system could meet all existing space heating, DHW and process requirements. For the hot water system, existing steam space heating systems must be converted at four buildings. The cost of conversion was included in the capital cost estimates for the substations. Process requirements for laundry and kitchen uses at two of the sites could not be converted to hot water and must be served by existing steam boilers.

Capital Cost

The capital costs for the distribution network and building substations were estimated to be 29% higher for the steam system than for the hot water system ($3.2 million vs. $2.5 million in 1987 dollars). Lower piping cost was the major cost advantage of the hot water distribution system.

Heat Loss

The estimated heat losses in the distribution network for the steam system were more than double those for the hot water system (15% of delivered energy compared to 7%). Valued at the cost of wood-chip base-load fuel ($13/MWh including boiler efficiency), these line losses would cost $48,000 annually for the steam system and $22,000 for the hot water system, for a difference of $26,000 per year. Steam system losses would be greater if a rigorous maintenance program was not followed.

Maintenance and Operating Costs

The maintenance and operating costs for the steam system were estimated to be twice those for a hot water system ($110,000/yr vs. $55,000/yr). The estimates were based on a factor of 2.5% of capital costs annually for the steam system plus the salary of one maintenance engineer. The difference in costs between the two systems was based mainly on the

Table 3.1

Summary of Comparison of Steam and Hot Water DH Systems
for New Downtown Charlottetown Systems

System Configuration: 3,866 meters
41 Connected Sites
Peak Load: approximately 12 MW
Delivered Energy: 25,000 MWh

	Steam System	Hot Water System
User Requirements	Meets all space heat, DHW and process needs	Cannot meet process needs at two sites (Existing boilers left to supply steam)
Capital Cost (1987 $)		
Distribution Network	$2,226,700	$1,349,600
Substations	951,200	1,121,400
Total	$3,177,900	$2,471,000
Heat Loss	15% of delivered energy plus leakage ($48,000/yr)	7% of delivered energy ($22,000/yr)
Maintenance and Operating Costs	$110,000/yr (2.5% of capital cost & salary of maintenance engineer)	$55,000/yr (1.0% of capital cost plus salary of maintenance engineer)
Supply Reliability	High	High
Durability	20-30 years (highly dependant on regular maintenance)	30-40 years
Metering	Accuracy +/- 10% Depending on meter and application	Accuracy +/- 2%
Leak Detection	None	Integral electronic system
Cogeneration	Limited opportunity	Well suited
Boiler Plant	High Capital Cost Higher operating costs Less efficient	Lower capital cost Lower operating costs More efficient
Availability of Technology	Proven, widely available	Proven, limited availability in Canada

greater number of mechanical parts requiring attention and the water treatment required in the steam system.

Life Cycle Costs

The combined impact of capital costs, heat losses and maintenance costs is illustrated in the life cycle costing in Table 3.2. The life cycle costs for hot water were potentially 45% lower than for steam.

Table 3.2

Life Cycle Costs for the Charlottetown System

	Steam	Hot Water
Capital Cost	$3,177,900	$2,471,000
Annual Amortization[1]	$ 373,300	$ 290,000
Operating and Maintenance	110,000	55,000
Heat Losses	48,000	22,000
Annual Cost	$ 531,000	$ 367,200

[1] Amortized at 10% for 20 years.

Supply Reliability

Both systems can be expected to provide a high degree of supply reliability.

Durability

Although the longevity of distribution systems cannot be predicted with precision, it was reasonable to expect hot water systems to last longer than steam systems. Experience has shown that steam systems may last 20-30 years and hot water systems 30-40 years. The durability of steam systems is greatly influenced by the level of attention to operating and maintenance requirements in such areas as make-up water quality and maintenance of mechanical parts.

Metering

The hot water system substations incorporate heat meters with reasonable levels of accuracy (+/- 2%) on which to base monthly billings for delivered energy. The steam system includes expensive, accurate steam flow meters only at the two sites with process requirements. The remaining sites utilize condensate return flow meters that would be adequate

but less accurate for measuring energy consumption.

Leak Detection

No leak detection system was incorporated in the steam system. The hot water system incorporated an integral, automatic leak detection system which would be triggered by leakage through either the outer casing or carrier pipe.

Cogeneration

The plant providing thermal energy for the steam system would have a limited ability to incorporate cogeneration because a relatively high temperature/pressure supply would be required by the DH network. The hot water system would have a relatively low operating temperature and be well suited for supply from a cogeneration plant.

Boiler Plant

For a new Charlottetown system, the boiler plant to be constructed for a steam system would be more expensive to construct and operate and would be less efficient (without additional economizers and controls) than a thermal plant built to serve a hot water system.

Availability of Technolog

At the time of this report, the technology of steam distribution systems was well proven in Canada. Engineering services, materials and equipment required for the implementation of a steam system were widely available. Although widely accepted in Europe, hot water distribution technology had only recently been proven in multiple-building Canadian applications. There was therefore limited familiarity with the technology within the engineering community and a considerable effort would be required to identify cost effective materials and equipment that meet code requirements.

3.3 McMaster University

3.3.1 Description of Site

McMaster University in Hamilton, Ontario has an extensive central heating and cooling system. The layout of the system is illustrated in Figure 3.2. The preliminary design work presented in the study described different options for a replacement of the system based on the assumption that the existing system was worn out.

At the time of this report, the steam system was generally located in large tunnels (approximately 3x3 m) which were located 3 m underground. Parts of the system were directly buried.

The total connected load was 33MW. The buildings currently supplied with heat consisted of campus buildings and a hospital. The hospital was not part of the university and the energy consumption was metered and billed. The remaining 33 substations did not have individual metering. Some buildings had two substations, while in other areas one substation served two buildings. To simplify the analysis, the total energy consumption on the campus was divided equally among the buildings to establish an average energy consumption per substation.

3.3.2 Comparison of Steam and Hot water Distribution

Table 3.3 presents a summary of the comparison of the two preliminary designs for a hypothetical retrofit project of the entire McMaster University steam distribution system. Each portion of this comparison is discussed below.

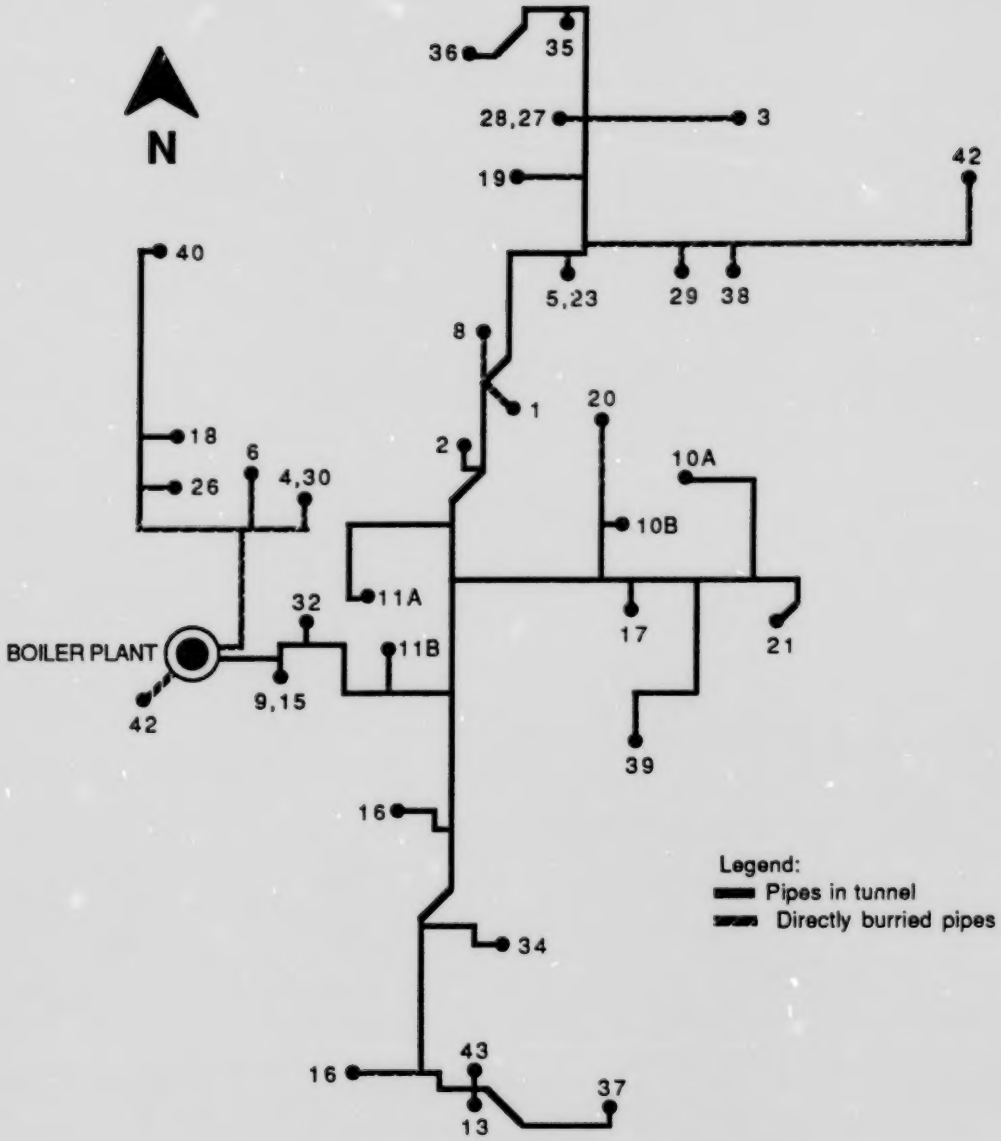
System Configuration

The McMaster University DH systems consisted of 34 sites (33 campus buildings and a hospital) connected through a 3,612 meter distribution network. The peak load was approximately 33 MW and the annual delivered energy was 72,000 MWh.

User Requirements

The proposed replacement of the existing steam distribution system would continue to meet all current space heating, DHW, sterilization and steam table needs. The hot water system would require a 1 MW steam boiler for the hospital which was included in the capital cost estimate.

Figure 3.2



McMaster University
District Heating System
Layout and Subscribers

Capital Cost

Assuming replacement of all piping and substations in the existing system, the hot water option would have a capital cost 10% lower than the steam option ($3.1 million vs. $3.4 million). If the $600,000 cost to convert the boiler plant to serve a hot water system is included, the investment cost of the hot water option would be 8% ($261,000) higher. However, operating efficiency could also be increased.

Heat Loss

The estimated system heat losses for the steam system were almost three times those for the hot water system (7% vs. 3% of delivered energy). At a fuel cost of $20/MWh (after including boiler efficiency), the losses translated into annual costs of $100,000 and $44,000, respectively. Steam system losses would be greater if a vigorous maintenance program was not followed. Note that the estimated heat losses were approximately half those of the Charlottetown system because almost 3 times the energy would be delivered over approximately the same distance.

Maintenance and Operating Costs

The steam system was estimated to incur twice the annual level of maintenance and operating cost of the hot water system ($115,000 vs. $60,000). The steam system estimate was based on 2.5% of capital cost and the hot water system estimate on 1.0% of capital cost plus the salary of one maintenance engineer.

Life Cycle Costs

The life cycle costs for the two systems are illustrated in Table 3.4. The life cycle costs were 16% higher for the steam system than for hot water.

Supply Reliability

Both systems were expected to provide dependable supply of thermal energy to the connected sites.

Durability

Based on experience, it was expected that hot water systems would last longer than steam systems (30-40 years vs. 20-30 years).

Table 3.3

Summary of Comparison of Steam and Hot water DH System for McMaster University Retrofit System

System Configuration:	3,612 meters 43 Connected Sites Peak Load: approximately 33 MW Delivered Energy: 72,000 MWh	
	Steam System	Hot Water System
User Requirements	Meets all space heat, DHW and process needs	Cannot meet steam demands at Hospital and steam tables at campus directly.
Capital Cost (1987 $)		
Distribution Network	$1,868,900	$1,429,700
Substations	1,548,800	1,648,800
Total	$3,417,700	$3,078,500
Heat Loss	7% of delivered ($100,000/year)	3% of delivered energy ($44,000+/year)
Maintenance and Operating Costs	$115,000 (2.5% of capital cost & salary of maintenance engineer)	$60,000 (1.0% of capital cost plus salary of maintenance engineer)
Supply Reliability	High	High
Durability	20-30 years (highly dependant on regular maintenance)	30-40 years
Metering	Accuracy +/- 10% Depending on meter and application	Accuracy +/- 2%
Leak Detection	None	Integral electronic system
Cogeneration	Limited opportunity	Well suited
Boiler Plant	Existing plant is satisfactory	$600,000 required for steam/hot water conversion. Heat exchangers, pumps, etc. included
Availability of Technology	Proven, widely available	Proven, limited availability

Table 3.4

Life Cycle Costs for the McMaster System

	Steam	Hot Water
Capital Cost	$3,417,700	$3,048,500
Boiler plant Modification	-	600,000
Annual Amortization[1]		
- System	$ 401,000	$ 358,000
- Boiler plant	-	70,000
Operation and Maintenance	115,000	60,000
Heat Losses	100,000	44,000
Annual Cost	$ 616,000	$ 532,000

[1] Amortized at 10% for 20 years.

Metering

With the hot water system, heat meters could be used to monitor all campus buildings (to help identify possible conservation measures) and to facilitate accurate billings to the hospital. With the steam system, less accurate condensate flow meters would provide indications of the level of thermal energy use for individual campus buildings. A steam meter would measure steam delivered to the hospital.

Leak Detection

The hot water system incorporates an electronic leak detection system while the steam system would not have a leak detection system because the high cost would not be justified.

Cogeneration

The steam plant which would supply the steam distribution option would provide limited potential for cogeneration. A hot water option would greatly enhance the potential attractiveness of a cogeneration plant. A back-pressure turbine for hot water district heating would yield 2-4 MWe during most of the year.

Boiler Plant

The existing boiler plant could be used for the steam system option. Approximately $600,000 in modifications would be required to convert the plant to serve a hot water system.

However, the plant could be expected to operate more efficiently when providing thermal energy to a hot water distribution system.

Availability of Technology

The technology of steam distribution systems was well proven in Canada. Engineering services, materials and equipment required for the implementation of steam system were widely available. Although widely accepted in Europe, hot water distribution technology had only recently been proven in multi-building Canadian operations. There was therefore limited familiarity with the technology within the engineering community. Effort would be required to identify cost effective materials and equipment that meet code requirements.

3.4 Impact of Using Low Temperature Hot Water

One alternative for both the McMaster and Charlottetown systems would be to use a low-temperature distribution system so that low-temperature heat sources could be utilized. The overall impact of reducing the design temperature would be:

1) Piping costs would be increased by approximately $370,000 in Charlottetown and $450,000 at McMaster to accomodate the increased flows required;

2) Direct connection would be impractical for both sites because of the large distribution systems and the risks associated with the internal building systems, especially the independently maintained systems in Charlottetown. Substation costs would therefore increase approximately $670,000 in Charlottetown and $860,000 at McMaster;

3) No significant change would be expected in heat losses. The reduction in losses from lower operating temperatures during the winter would be offset by the larger pipe sizes;

The levelized cost of low-temperature systems is compared with the medium temperature systems in Table 3.5. The levelized cost of the low-temperature system was estimated to be 33% and 29% higher than the cost of the medium temperature system for Charlottetown and McMaster, respectively. The investment costs for low-temperature systems would be lower where direct connection is practical. However, this would normally only be feasible for much smaller systems.

Table 3.5

Levelized Cost of Low-Temperature and Medium Temperature Systems

	Charlottetown		McMaster	
	Low-Temp.	Med-Temp.	Low-Temp.	Med-Temp.
	(000)			
Capital Cost	$3,511	$2,471	$4,958	$3,648
Annual Amortization[1]	$ 412	$ 290	$ 582	$ 428
Operating and Maintenance	55	55	60	60
Heat Losses	22	22	36	36
Annual cost	$ 489	$ 367	$ 678	$ 524

[1] Amortized at 10% for 20 years.

4.0 Overall Conclusions

The first case study was based on a proposed new municipal district heating (DH) system for downtown Charlottetown, Prince Edward Island. The 3.9 km system would connect 41 sites with a peak load of 12 MW. The evaluation of the preliminary designs for steam and hot water systems led to the conclusion that the hot water system would be preferred based on most technical, economic and operating criteria that were considered.

The second case study was based on the replacement of the steam distribution system at McMaster University in Hamilton, Ontario. The existing 3.6 km system connected 33 campus buildings and a hospital with a combined peak load of 33 MW. The assessment of the steam and hot water designs prepared for the replacement of the existing system indicated that:

1) The steam option would have a lower total capital cost because boiler plant modifications would be required to supply hot water;

2) The hot water option would provide for greater system efficiency and lower operating costs based on load characteristics typical of space heating needs;

3) The steam system was slightly more flexible when steam demands could be connected;

4) The hot water option would have a lower life-cycle cost.

The overall conclusions that were reached regarding the steam and hot water alternatives for distribution of thermal energy to multiple sites were:

1) Hot water systems provided more opportunities to incorporate cogeneration and low grade thermal energy (e.g municipal waste), which would enhance overall project attractiveness.

2) Hot water was expected to be the lowest capital cost option for the construction of many new DH systems. The piping network was considerably less expensive for hot water than for steam systems (39% lower in the Charlottetown design) while the sub-stations costs for steam and hot water were approximately equal.

   For system replacements, it was more difficult to generalize as to which option was likely to have the lower capital cost. Principle factors that determine

the total capital cost are:

1) Layout and condition of the existing distribution system;

2) Requirements to convert existing building space heating systems to hot water;

3) Condition and efficiency of the existing boiler plant;

4) Potential for cogeneration;

5) Potential for utilizing alternate fuels waste heat or available sources of low grade energy.

3) Hot water systems were expected to have lower operating costs than steam systems because of the following factors:

1) The heat losses in the distribution network are significantly lower, particularly for space heating loads;

2) Operating costs for such items as water treatment are significantly lower;

3) Maintenance labour, material and repair costs are significantly lower;

4) Boiler plant efficiency is usually higher.

4) Low-temperature (80-95^{o}C) hot water systems were evaluated as a specific system alternative. The investment costs were 35-42% higher and the levelized costs 29-33% higher for the low-temperature systems when compared to the medium-temperature systems. The investment costs for low-temperature systems would be lower where direct connection is practical. However, this would normally only be feasible for smaller systems.

Hot water systems were also expected to have a longer life than steam systems.

The general conclusion was that hot water distribution systems would have lower life cycle costs than steam systems for most space heating applications. Steam systems offer greater flexibility and may be used when special requirements, such as process steam loads, must be met.

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FINAL REPORT

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COMPARATIVE EVALUATION OF HOT WATER AND STEAM DISTRIBUTION SYSTEMS FOR DISTRICT HEATING

Summary

This study developed a comparative analysis of the relative merits and deficiencies of steam and medium temperature hot water technologies for linking a central plant (or plants) to thermal energy demands at multiple sites. Steam and hot water technologies were compared in three ways:

1) A comparison of design principles associated with each technology was developed.

2) Preliminary designs were prepared and then compared for two case study sites: a replacement of an existing system and a proposed new system.

3) Overall conclusions were reached as to the comparative advantages and limitations of steam and hot water systems.

Findings:

The major design principles for steam and hot water thermal energy distributions systems were compared using the following topics:

1) Basic System Alternatives

2) User Requirements

3) Connections to Users

4) Distribution System Configuration

5) Production Plants

6) Maintenance and Operations

7) Availability of Technology

A more detailed discussion of the design principles for each system in included in Appendix 2.

The first case study was based on a proposed new municipal district heating (DH) system for downtown Charlottetown, Prince Edward Island. The 3.9 km system would connect 41 sites with a peak load of 12 MW. The evaluation of the

preliminary designs for steam and hot water systems led to the conclusion that the hot water system would be preferred based on most technical, economic and operating criteria that were considered.

The second case study was based on the replacement of the steam distribution system at McMaster University in Hamilton, Ontario. The existing 3.6 km system connected 33 campus buildings and a hospital with a combined peak load of 33 MW. The assessment of the steam and hot water designs prepared for the replacement of the existing system indicated that:

1) The steam option would have a lower total capital cost because boiler plant modifications would be required to supply hot water;

2) The hot water option would provide for greater system efficiency and lower operating costs based on load characteristics typical of space heating needs;

3) The steam system was slightly more flexible when steam demands could be connected;

4) The hot water option would have a lower life-cycle cost.

The overall conclusions that were reached regarding the steam and hot water alternatives for distribution of thermal energy to multiple sites were:

1) Hot water systems provided more opportunities to incorporate cogeneration and low grade thermal energy (e.g municipal waste), which would enhance overall project attractiveness.

2) Hot water was expected to be the lowest capital cost option for the construction of many new DH systems. The piping network was considerably less expensive for hot water than for steam systems (39% lower in the Charlottetown design) while the sub-station costs for steam and hot water were approximately equal.

   For system replacements, it was more difficult to generalize as to which option was likely to have the lower capital cost. Principle factors that would determine the total capital cost are:

   1) Layout and condition of the existing distribution system;

   2) Requirements to convert existing building space heating systems to hot water;

3) Condition and efficiency of the existing boiler plant;

4) Potential for cogeneration;

5) Potential for utilizing alternate fuels, waste heat or available sources of low grade energy.

3) Hot water systems were expected to have lower operating costs than steam systems because of the following factors:

1) The heat losses in the distribution network are significantly lower, particularly for space heating loads;

2) Operating costs for such items as water treatment are significantly lower;

3) Maintenance labour, material and repair costs are significantly lower;

4) Boiler plant efficiency is usually higher.

4) Low-temperature (80-95^{o}C) hot water systems were evaluated as a specific system alternative. The investment costs were 35-42% higher and the levelized costs 29-33% higher for the low-temperature systems when compared to the medium-temperature systems. The investment costs for low-temperature systems would be lower where direct connection is practical. However, this would normally only be feasible for smaller systems.

Hot water systems were also expected to have a longer life than steam systems.

The general conclusion was that hot water distribution systems would have lower life cycle costs than steam systems for most space heating applications. Steam systems offer greater flexibility and may be used when special requirements, such as process steam loads, must be met.

EVALUATION COMPARATIVE DES SYSTEMES DE DISTRIBUTION A EAU CHAUDE ET A VAPEUR POUR FINS DE CHAUFFAGE URBAIN

SOMMAIRE DE LA DIRECTION

Cette étude compare les avantages et désavantages relatifs des technologies utilisant soit la vapeur soit l'eau chaude maintenue à température moyenne comme caloporteurs approvisionnant plusieurs points ou sites d'utilisation d'énergie thermique à partir d'une (ou plusieurs) centrale thermique.

La comparaison des technologies utilisant soit la vapeur soit l'eau chaude comme caloporteur à été effectuée à partir de trois types d'analyse:

1) Les principes propres à la conception des sytèmes utilisant chacune des technologies ont d'abord été comparés.

2) Ces principes ont ensuite été appliqués dans la conception préliminaire des systèmes à vapeur et à eau chaude requis pour desservir deux emplacements sélectionnés comme études de cas: un premier site où l'installation d'un nouveau système de distribution était préconisé et un deuxième site où le système existant devait être remplacé.

3) Des conclusions générales ont ensuite été établies sur les limites et avantages respectifs des systèmes à vapeur et à eau chaude.

RESULTATS

Les principaux principes utilisés dans la conception des systemes de distribution d'énergie thermique sous forme de vapeur ou d'eau chaude ont été comparés à l'aide des critères suivants:

1) Les alternatives de base offerte par le système;
2) Les besoins de l'utilisateur;
3) Les raccordements avec les points ou equipements alimentés par l'énergie thermique;
4) La configuration du système de distribution;
5) Les centrales thermiques;
6) L'entretien et l'exploitation;
7) La disponibilité de la technologie.

L'annexe 2 présente les éléments d'une discussion plus détaillée des principes de conception retenus pour chacun des systèmes.

La premiere étude de cas réfère au nouveau système de chauffage urbain proposé pour dessereir le centre-ville de Charlottetown à l'Ile du Prince Edouard. Le système de distribution d'une longueur de 3.9 km se devait d'approvisionner 41 emplacements ou sites d'utilisation dont la demande de pointe totale était de 12 MW.

En comparant la conception préliminaire de ce qu'auraient été le système à vapeur et le système à eau chaude requis pour desservir ce réseau, il est possible de conclure à la supériorité du système à eau chaude face à la plupart des critéres techniques, économiques et opérationnels considérés.

La seconde étude de cas réfère au remplacement du système de distribution de vapeur utilisé à l'Université McMaster de Hamilton en Ontario. Le système en place d'une longueur de 3.6 km approvisionnait un hôpital et 33 édifices situés sur le campus dont la demande de pointe combinée s'élevait à 33 MW.

L'évaluation de la conception préliminaire des systèmes à vapeur et à eau chaude requis dans ce cas à révélé que:

1) L'option "vapeur" aurait été moins coûteuse en termes d'investissement initial total que l'option "eau chaude" qui n'aurait pu être exploitée sans modifications aux chaudières.

2) L'option "eau chaude" aurait toutefois contribué à doter la système d'une plus grande efficacité et de moindres coûts d'exploitation en raison d'une plus grande conformité aux caractéristiques propres de la demande thermique associée au chauffage des locaux.

3) Le système de distribution à vapeur semblait toutefois plus flexible pour desservir les besoins éventuels en vapeur de certains édifices.

4) Lorsqu'actualisés sur toute la vie utile du système, les coûts totaux associés à l'option "eau chaude" s'avéreraient toutefois moins élevés.

Les conclusions globales de l'étude sur le positionnement relatif des alternatives "vapeur" et "eua chaude" comme caloporteurs utilisés pour la desserte en énergie thermique de plusieurs points ou sites d'utilisation sont les suivantes:

1) Les caractéristiques propres des systèmes à eau chaude les rendent plus aptes à une intégration éventuelle à des systèmes de production mixte d'énergie (cogénération) ou à des systèmes alimentés à partir d'énergie de qualité inférieure telle les déchets municipaux. Ces opportunités, lorsqu'exploitées adéquatement, viendraient augmenter l'attrait économique global des projets considérés.

2) Les systèmes à eau chaude s'avéreraient l'option la moins coûteuse en termes de coûts en capital requis et ce, pour plusieurs nouveaux systèmes de chauffage urbain. Le réseau de conduites des systèmes à eau chaude s'est avéré significativement moins coûteux que celui requis dans des systèmes à vapeur (39% moins coûteux dans le cas de Charlottetown). Les coûts associés aux sous-stations se sont avérés presques équivalents pour les deux types de systèmes.

Il à été toutefois plus difficile de déterminer laquelle des deux options s'avérerait <u>en général</u> la plus économique en termes d'investissements initiaux lors du remplacement de systèmes de distribution déjà en place. Les principaux determinants des coûts en capitaux dans ce cas sont:

1) La configuration et l'état du système de distribution existant;

2) La nécessité de convertir à l'eau chaude les équipements de chauffage existant dans les édifices desservis;

3) L'état et le degré d'efficacité de la centrale thermique existante;

4) Le potentiel de production mixte d'énergie (cogénération);

5) Le potentiel d'utilisation de sources d'énergie alternatives, de chaleur résiduelle ou de toute source d'énergie de qualité inférieure disponible.

3) Les systèmes à eau chaude s'avéreraient moins coûteux en termes de coûts d'exploitation, et ce, pour les raisons suivantes:

1) Les pertes thermiques dans le réseau de distribution sont significativement moins

élevées et ce, particulièrement pour la desserte du chauffage des locaux;

2) Les coûts d'exploitation liés au traitement de l'eau sont significativement moins eleves;

3) Les coûts en personnel d'entretien, en matériaux et en réparations sont aussi significatifment moins élevés.

4) L'efficacité de la centrale thermique est généralement plus élevée.

4) La vie utile des systèmes à eau chaude serait en outre plus longue que celle des systèmes de distribution à vapeur.

5) Les systèmes de distribution à eau chaude maintenue à basse température (80-95°C) ont aussi été évalués à titre d'alternative spécifique. Lorsque comparés à ceux des systèmes à eau chaude maintenue à température moyenne, les coûts d'investissement initiaux et les coûts annualisés des systèmes à basse température seraient respectivement de 35%-42% et de 29%-33% plus élevés. Les coûts d'investissement initiaux des systèmes à eau chaude à basse témperature seraient toutefois inférieurs dans les cas où un raccordement direct serait possible avec les équipements utilisant l'eau chaude. Ce ne serait le cas toutefois que pour les systèmes de petite capacité.

Enfin, la conclusion générale de l'étude peut se lire comme suit: lorsqu'évalués sur la totalité de la vie utile des systèmes, les coûts actualisés des systèmes de distribution à eau chaude seraient moins élevés que ceux des systèmes de distribution à vapeur pour la plupart des applications de chauffage des locaux. Plus flexibles, les systèmes de distribution à vapeur peuvent toutefois être avantageusement utilisés lorsque des besoins spécifiques, tels l'utilisation de vapeur dans des procédés de production, doivent être comblés.

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A Comparative Evaluation of Hot Water and Steam Distribution Systems for District Heating

1.0 Introduction

1.1 Project Objective

At the time of this study, medium temperature hot water technology was well established in Europe for the distribution of thermal energy from a central heating plant to multiple building sites. Steam technology, on the other hand, was dominant in North America for such district heating applications. During the past 5-10 years, there has been growing interest in the United States and Canada in determining the appropriateness of the European hot water technology as an alternative for the replacement of existing, and the development of new, district heating (DH) systems.

This study was conducted to assist those who are involved in the operation, assessment and investment decisions related to existing and new DH systems in Canada. Based on the statement of work established for the study, the project objective was:

> To describe the alternative steam/and hot water distribution technologies and to develop a comparative analysis for the two systems.

Since few Canadian engineers and district heating system operators have direct experience with hot water distribution technology, the study should also contribute to a balanced and comprehensive assessment of the options.

The comparison of steam and medium temperature distribution technologies was carried out in three phases:

1) The design principles associated with each were developed and compared;

2) Preliminary steam and hot water distribution designs were prepared and then compared for two case study sites: replacement of an existing system and a new system;

3) Overall conclusions were reached as to the

comparative advantages and limitations of steam and hot water systems for typical Canadian applications.

1.2 Background

Most district heating (DH) systems in Canada involve the group central heating approach. With this approach, a relatively small number of buildings (typically 20 to 100) are linked to a central heating plant. District heating systems currently operating in Canada are generally of one of the following types:

1) Those designed primarily for supplying space heat and domestic hot water for buildings;

2) Those designed primarily for supplying thermal energy for industrial process requirements.

There are several hundred of each type of system in place. Examples of the first type include systems at hospitals, universities, military bases, correctional institutions, government building complexes and office buildings in the downtown cores of major cities. Most multiple-building industrial sites would provide examples of the second type.

At the time of this study, the technology of steam as a heat transport medium was mature in Canada. The principles of design, construction, operation and maintenance of steam distribution systems were well understood and provided the basis for almost all group central systems in the country. On the other hand, the use of hot water distribution systems was found in only a very limited number of applications in Canada. Most of these were based on high temperature hot water. The medium temperature (120^{0}C) technology, which had been developed, refined and proven in Europe during the past 40 years, had just begun to be transferred to Canada. Two recent projects in Prince Edward Island, for example, had helped transfer the technology into the Canadian context of material and equipment sources, regulatory codes, and engineering and construction practices.

DH activity in Canada during the next 5-10 years was expected to focus on:

1) The evaluation and implementation of opportunities for improving the operating efficiency of existing DH systems;

2) The replacement of aging DH systems; and

3) The identification of new district heating systems that could be based on low-cost conventional and alternative fuel sources and/or cogeneration systems;

As the owners and operators of existing and potential DH systems carry out these three types of projects, they should be familiar with all possible design approaches. The results of this study should help identify where hot water systems will have a clear advantage over steam systems and confirm the appropriateness of steam for other applications.

The challenge in the design process is one of applying an understanding of the technical, economic and organizational principles associated with the two distribution technologies. This study was conducted to illustrate the major considerations to be taken into account when selecting between steam and hot water as media for district heating.

1.3 Study Methodology

The study involved six steps:

1) The principal distribution alternatives used for district heating (and their common variations) were described.

2) The principles and parameters associated with the design of steam and hot water distribution systems were discussed and evaluated in the context of the technical, economic and organizational environment in Canada.

3) Preliminary designs of the most representative steam and hot water technologies were prepared for one new DH project and one replacement assessment of an existing system.

4) The principles and parameters discussed in step two were then applied to illustrate the relative advantages and disadvantages of steam and hot water for the projects under consideration.

5) Documentation of the work carried out was prepared for presentation in this final report.

6) A summary report for distribution to the engineering community and other relevant decision makers was prepared and is available under separate cover.

1.4 Study Framework

The study was conducted within a five part framework as follows:

1) Objective of the Design Process

To determine the optimal system configuration for meeting thermal energy requirements for multiple facilities linked to a central plant.

2) DH System Components

The DH system was described based on the following components:

a) Source of Thermal Energy

- Heat only or cogeneration boiler plants fuelled by conventional or alternative fuels (or a combination).

- Heat recovery systems and other sources of low grade thermal energy.

b) Distribution Network

- Piping network to supply thermal energy to connected facilities.

c) Sub-Station

- Interface to transfer thermal energy from the distribution system to the energy system(s) of the connected facilities.

3) Design Decisions

The major design decisions that were identified and discussed included:

a) Optimization of the size, location and fuel source(s) for the heat plant;

b) Assessment of the feasibility of cogeneration;

c) Selection of steam or hot water as the distribution medium.

d) Selection of sites to be connected to the system.

e) Optimization of the distribution system (routing,

pipe sizes and other characteristics) to satisfy the needs at the connected facilities.

The sequence in which these decisions are made depends on the specific design situation. In certain system replacement situations, for example, no flexibility may exist with respect to the sources of thermal energy or the selection of sites to be connected. In other cases, the decision regarding whether steam or hot water is preferable may be the first decision reached. Inter-relationships among the five decisions are also discussed. For example, the feasibility of cogeneration is enhanced with hot water systems as lower turbine outlet temperatures are possible. The number and location of sites feasible for connection may also be dependent on the selection of steam versus hot water as a distribution medium.

4) Design Criteria

The fourth part of the study framework consisted of the delineation of the decision criteria. The most important criterion related to the relative financial attractiveness of technically viable options based on estimates of capital, operating and maintenance costs. The criteria of system reliability and life expectancy were less certain. In certain situations criteria can include the compatibility of options with government initiatives such as support for biomass or municipal waste plants.

5) Design Process

The fifth part of the study framework involved developing an outline of the design process. The four steps of this process were identified as:

a) Establishment of the parameters and characteristics of the proposed project including:

- project type (new/retrofit)
- thermal energy requirements (by site)
    - . process, space heat, etc.
    - . peak demand
    - . annual demand
    - . temperatures (maximum and minimum)
    - . pressures (existing system)
    - . pattern of demand (e.g., seasonality)
- cooling requirements (by site)
- nature and condition of existing heating system (by site)
- cost of available fuels and energy sources (e.g.,

heat recovery opportunities)
- institutional parameters (e.g., buy-back rates and back-up arrangements for cogeneration opportunities)
- opportunities for thermal storage

b) Development of the preliminary design of principle steam and hot water system options, highlighting:

- system layout
- pipe sizing
- temperatures (supply and return)
- pressures
- capital costs
- operating and maintenance costs

The preliminary design must address the considerations and variables detailed in Appendix 2 of this report, including:

- piping and installation materials
- installation configurations
- thermal expansion
- leak detection
- heat loss
- supply reliability
- configuration of building substations
- metering of thermal energy provided

c) Assessment of options based on the criteria listed in the third part of the study framework, and selection of the option that best meets the criteria.

d) Preparation of the detailed design of the recommended system, including attention to such factors as the exact location of utilities in the streets and sub-station requirements at specific facilities.

1.5 Study Team

This study was managed by IEA Consulting Group Ltd., a firm with extensive experience in directing assessments of energy management technologies in general and district heating projects in particular. The technical and economic analysis in the study were directed by AFE Engineering Inc. (AFE), the Canadian subsidiary of one of Sweden's leading consulting engineering firms. AFE was assisted by Maunder and Britnell Engineering Ltd., a consulting engineering firm with significant experience related to Canadian district heating

systems.

1.6 Organization of This Report

Section 2 presents a comparison of the design principles for steam and hot water systems. Section 3 compares the steam and hot water designs developed for the two case studies. In Section 4, overall conclusions as to the relative merits and disadvantages of steam and hot water systems are presented.

Appendix 1 is a glossary of frequently used terms related to district heating systems. Appendix 2 contains a brief introduction to design principles for steam and hot water systems, from which the comparison in Section 2 was derived. Appendices 3 and 4 provide details of the preliminary designs prepared for the case studies. Appendix 5 provides a summary of the current status of high-temperature hot-water boiler applications in Canada.

2.0 Comparison of Design Principles of Steam and Hot Water Distribution Systems

2.1 Purpose of This Section

This section presents a comparison of design principles for steam and hot water distribution systems. This comparison was based on the detailed discussion of design principles contained in Appendix 2. Readers who are not familiar with the two technologies are advised to review Appendix 2 before they consider the comparative presentation in this section.

2.2 Framework for Comparison of Design Principles

The comparison of principles which follows deals with seven major aspects of distribution system design:

1) Basic System Alternatives
2) User Requirements
3) Connections to Users
4) Distribution System Configuration and Parameters
5) Production Plants
6) Maintenance and Operation
7) Availability of Technology

2.3 Basic Systems Alternatives

Most Canadian district heating systems utilize either high or low pressure steam. Hot water systems are typically low or medium temperature/pressure; however, high temperature/pressure systems are used for special applications.

Steam Systems

Steam distribution systems are used for space heating, absorption cooling, domestic hot water (DHW) and industrial process applications. For small systems where process steam is not required, low pressure steam (up to 2 bar g, 30 psig) is utilized. Most systems, however, operate at 7-14 bar g (100-200 psig) and 170 - 200^{o}C. Most steam systems include a

condensate return line and are installed in box conduits and tunnels or are directly buried.

Hot Water Systems

Hot water systems are used primarily to meet space heating and DHW requirements. The basic system alternatives are:

1) Low temperature/pressure:

   80-95°C peak supply temperature, 2-10 bar g (30-145 psig) pressure, direct connection.

2) Medium or intermediate temperature/pressure:

   100-120°C peak supply temperature, 5-25 bar g (75-360 psig) pressure, closed loop, direct or indirect connection.

3) High temperature/pressure:

   130-200°C peak supply temperature, 20-40 bar g (290-580 psig) pressure, closed loop, indirect connection.

Low temperature systems are usually found when only a few buildings are connected. Intermediate temperature systems are the most common for DH applications. High temperature systems are used infrequently, typically for process applications and large DH transmission mains.

Most hot water distribution systems use directly buried pipe. However, the box conduit installation technique is common for large pipe (600mm diameter and larger).

2.4 User Requirements

Most non-residential buildings in Canada utilize hot water for their space heating systems. Normal operating temperatures in winter range from 80 to 95°C , with a design temperature drop of 10-20°C . Some older buildings, such as hospitals, are partly or totally heated with steam. Absorption chillers using steam are operated at a small number of buildings.

Steam Systems

A 7-14 bar g (100-200 psig) steam system can meet space heating, domestic hot water (DHW), cooling (through absorption chillers) and most process requirements. Steam can also used be used for humidification, kitchen steam

tables and hospital sterilization requirements.

A steam distribution system can serve buildings with either steam or hot water space heating systems. When steam is used for space heating, the steam pressure from the distribution system is reduced at a reducing station before it enters the building. For DHW and a hot water space heating system, the steam from the distribution system is passed through steam to hot water heat exchangers.

Hot Water Systems

Intermediate and low temperature hot water system can serve space heating, DHW and some process requirements. The buildings being connected must have space heating systems that can be supplied from a hot water heat exchanger (e.g. hot water or air). Humidification can be provided through hot water humidifiers. If the buildings connected to hot water distribution systems have sterilization or other limited steam requirements, a small steam boiler or steam generator can be installed.

2.5 Connection to Users

Steam Systems

Figure 2.1 illustrates the schematic for a typical steam connection. Where steam is not used for process requirements, it is usually reduced to low pressure at the connection between the building and distribution system. It is then used for space heating (directly or through a heat exchanger) and DHW.

The condensate is typically collected in an open condensate tank and pumped through the condensate return pipe back to the boiler plant.

The thermal energy provided by a steam distribution system can be measured with a steam meter or a condensate meter. Steam meters are relatively expensive ($5,000 to $50,000). Condensate meters are less expensive; however, accuracy is reduced because of steam losses in the buildings and varying steam pressures.

Hot Water Systems

A hot water distribution system can be linked to a building through either a direct or indirect connection. With a direct connection, the hot water from the distribution system

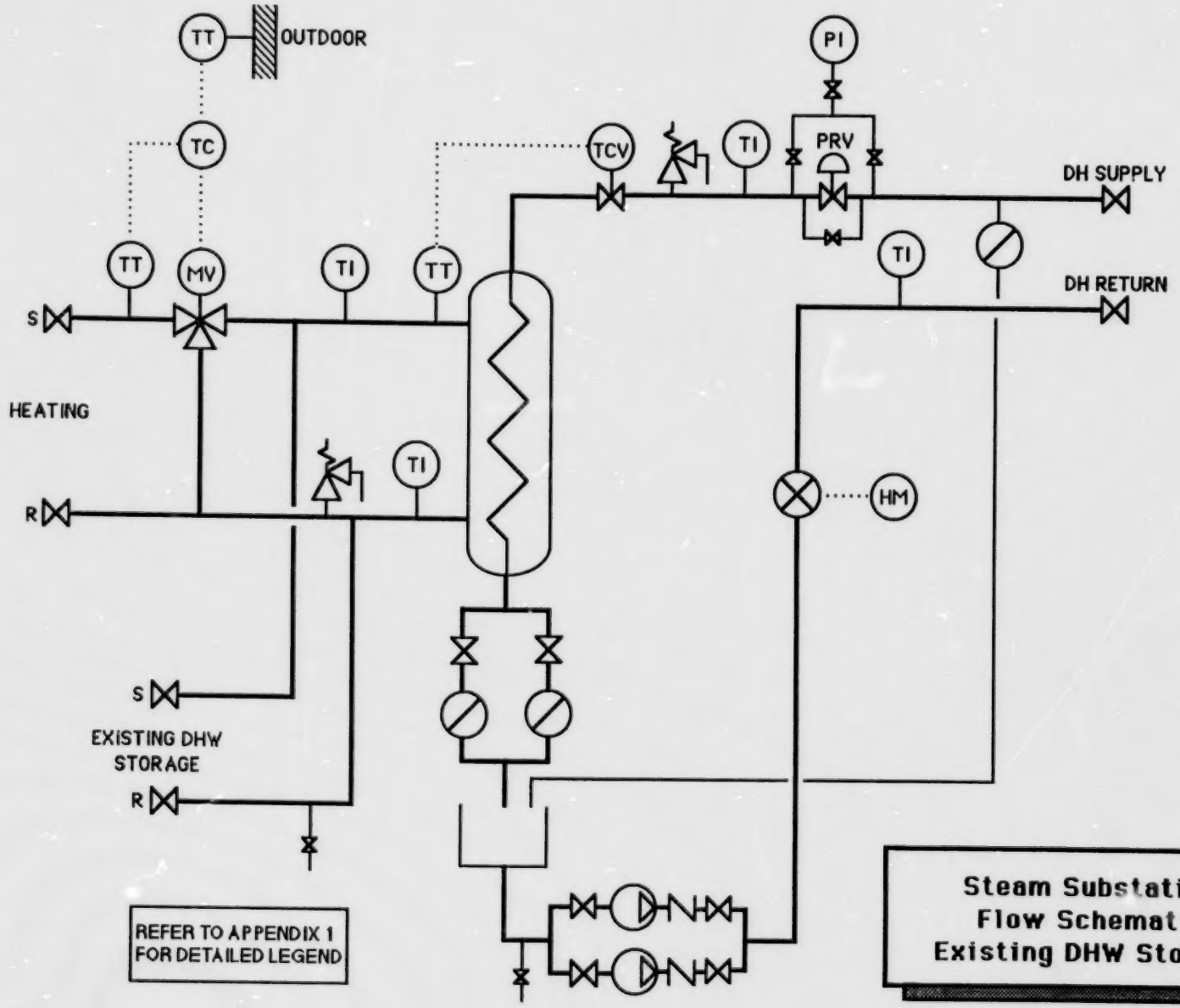


Figure 2.1

Steam Substation Flow Schematic Existing DHW Storage

is pumped through the space heating system in the building. With an indirect connection, heat exchangers linked to the building's space heating and DHW systems transfer the thermal energy from the distribution system to the building. For the majority of DH applications in Canada, the indirect connection approach is preferable because the heating systems of the buildings can be totally isolated from the distribution system and there is more flexibility in design and operation. The schematics for the two types of systems are illustrated in Figures 2.2a and 2.2b.

In hot water systems, the energy delivered to a building is measured by a heat meter which consists of a flow meter, temperature sensors for the supply and return pipes and a integration unit (microprocessor) for calculating the thermal energy delivered to the building.

2.6 Distribution System Configuration and Parameters

2.6.1 Configuration

The most common installation configurations for both steam and hot water systems include:

1) Tunnel systems with insulated pipes attached to the ceiling, walls or floor.

2) Box conduits with the carrier pipe insulated with fibreglass and covered with asphalt paper (or equivalent).

3) Directly buried pipes.

   - Insulated with fibreglass, covered with sheet metal, poured in concrete and covered with a bituminous coating.

   - Steel-in-steel system

   - Steel pipe with polyurethane foam insulation and polyethylene casing

   - Steel pipe with fibreglass insulation and plastic coating (e.g. PEH or PVC).

The more common installations are illustrated in Figure 2.3. The specific options for steam and hot water are discussed below.

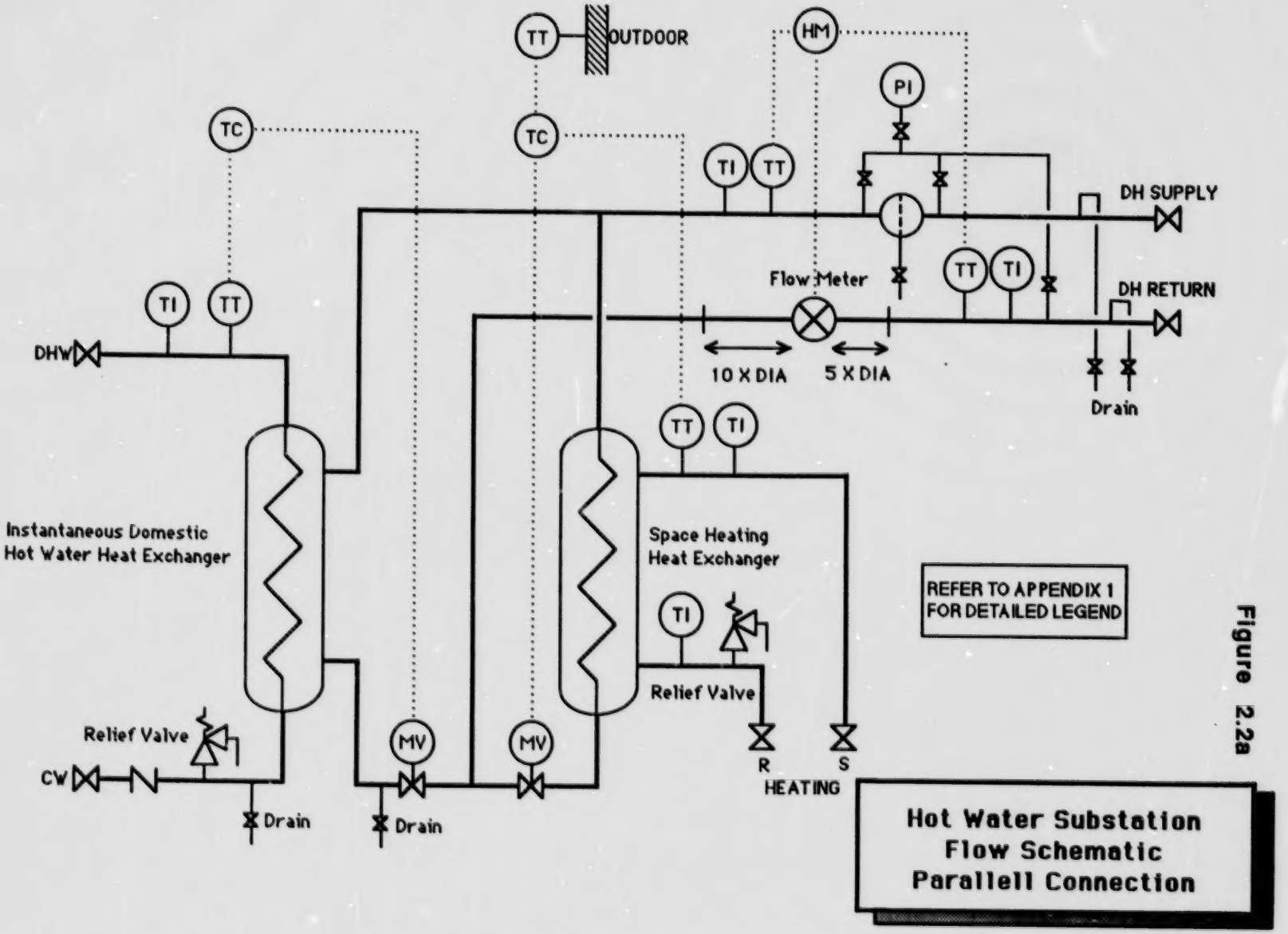


Figure 2.2a

Hot Water Substation
Flow Schematic
Parallell Connection

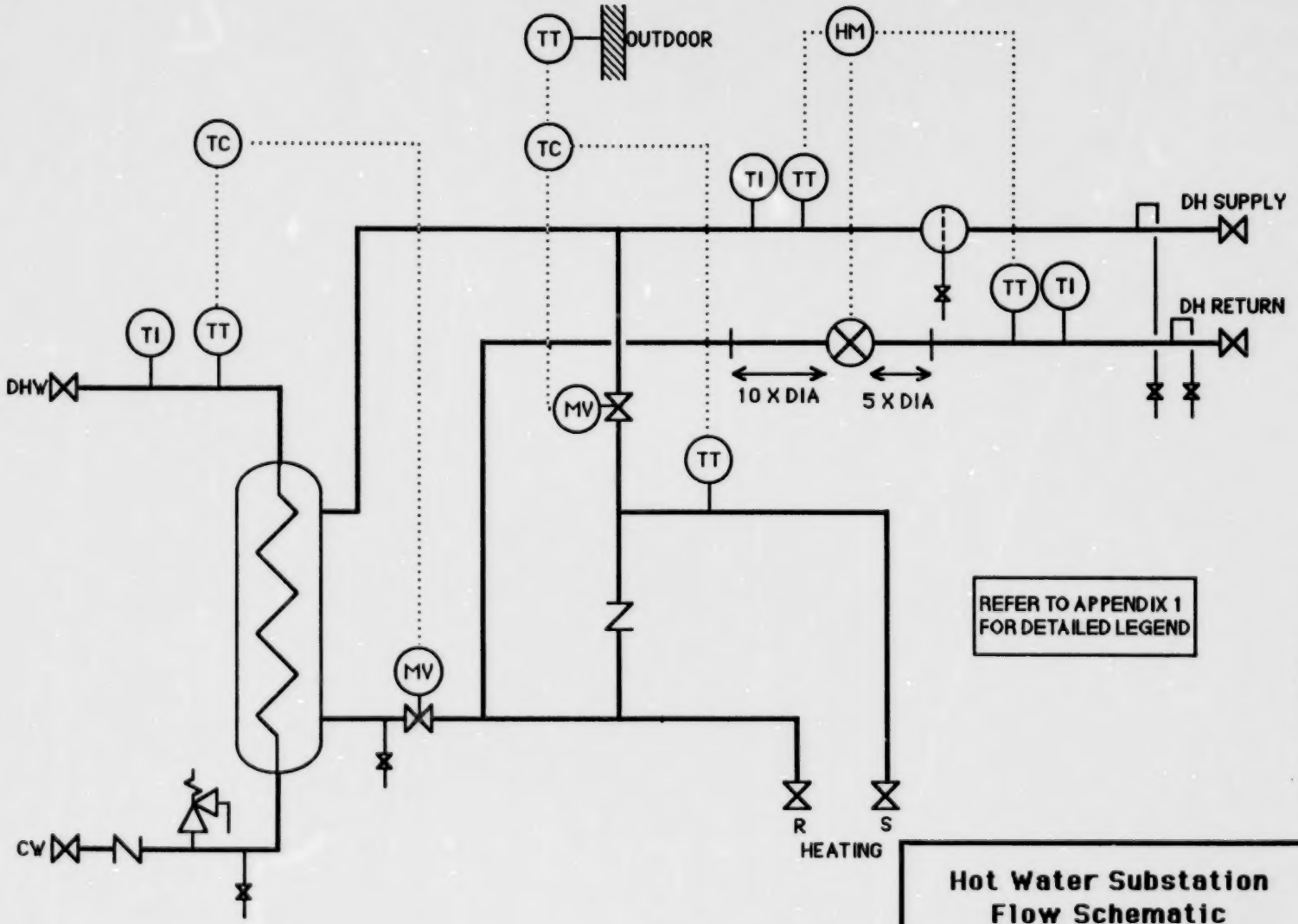


Figure 2.2b

Hot Water Substation
Flow Schematic
Direct Connection

Figure 2.3

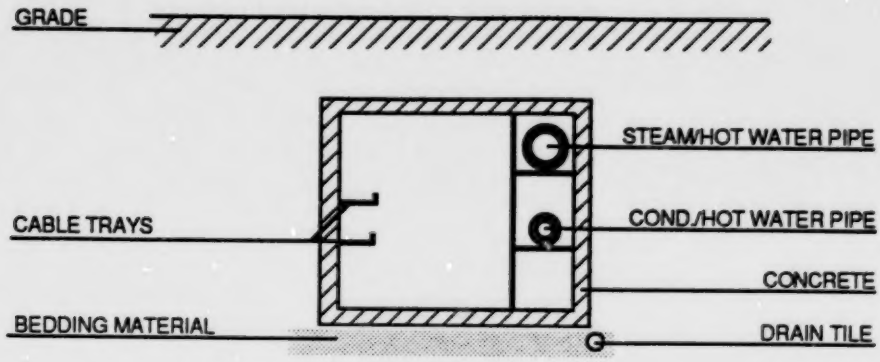


Fig. A - Tunnel

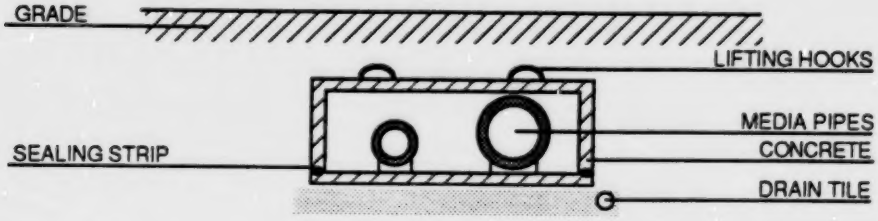


Fig. B - Box Conduit (Inverted tunnel)

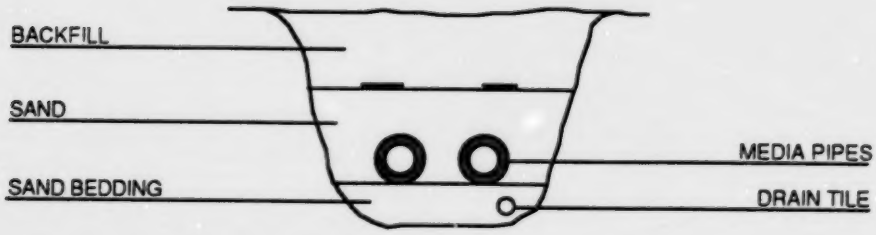


Fig. C - Direct Buried Pipes

Cross Section
Typical Pipe Installations

Steam Systems

The pipe used for steam distribution systems is usually Schedule 40 or 80 carbon steel. The condensate return pipe is typically Schedule 40 or 80 carbon steel or fibreglass reinforced plastic.

For a steam distribution system, complete manholes or concrete chambers must be built for traps, condensate tanks and pumps, sectioning valves and expansion joints.

Hot Water Systems

The piping materials used in hot water distribution systems include:

1) Preinsulated carbon steel carrier pipe with polyurethane foam insulation and polyethylene jacket.

2) Steel-in-steel systems with insulation between the steel carrier pipe and steel jacket pipe.

3) Concrete ducts with steel pipes insulated with fibreglass and covered with asphalt paper.

4) Copper pipe with fibreglass insulation and polyethylene jacket.

The most common of these four types is the preinsulated pipe which is installed in almost all cases in a directly buried configuration. In such systems, preinsulated fully-welded ball valves reduce the need for complete manholes or chambers.

2.6.2 Heat Loss

Steam Systems

Well maintained steam systems typically have average annual heat losses equivalent to 10% to 20% of the transferred thermal energy. During part load conditions the heat losses are substantially higher. Reasons for this higher level of heat loss with steam systems include:

1) Higher temperature of steam lines;

2) Exposure of spacers, hangers and supports;

3) Lower insulating value of fibreglass compared to polyurethane;

4) Leaking steam traps and condensate return pipes.

Hot Water Systems

Hot water systems typically have average annual heat losses of 4% to 10% of transferred energy, or approximately half the level of losses in steam systems. The major reasons for the reduced losses are:

1) Relatively low temperature of the media (hot water);

2) Systems are fully insulated;

3) High insulating value of polyurethane;

4) Closed loop systems with few mechanical components have low water losses.

2.6.3 Allowance for Expansion

Steam Systems

The degree of thermal expansion of a steam pipe is much greater than for a hot water pipe because of the higher temperature of the steam. Expansion can be compensated for in several ways, including:

1) Compensators

2) Expansion loops

3) Natural pipe flexibility

4) Swing joints

Various combinations can be used for each installation.

Hot Water Systems

Two main alternatives are used in hot water systems to allow for thermal expansion: free expansion and restrained expansion. With the free expansion approach, the piping can slide and the expansion is taken up in expansion loops and compensators. The restrained expansion approach is used for "bonded" systems. With this approach, which is usually used with preinsulated pipe, the carrier pipe is bonded to the insulation and the casing pipe so that the pressure of the surrounding soil restrains the expansion of the pipe.

2.6.4 Leak Detection

All directly buried systems require a method of detection to locate any system leaks before extensive damage is caused. Such leaks can occur from corrosion or other problems with the carrier pipe or from a break in the outer casing. Effective leak detection can greatly extend system life.

Steam Systems

Leak detection in steam systems is not common. Systems such as steel in steel systems may incorporate a second pipe inside the casing. If a leak does occur, the second pipe will collect the liquid and drain it to some point in the piping system (i.e. a manhole). The presence of water in this line would indicate a leak. Where box conduits have been used, another method is to draw a microphone through the empty conduit to detect any leaks.

Hot Water Systems

Because hot water systems are closed loops, significant leaks in carrier pipes can be detected by monitoring make-up water requirements. In addition, preinsulated pipe usually incorporates an integral electronic leak detection system. When leaks occur, wires located inside the casing short circuit and the location of leaks through the casing or carrier pipe can be determined within a few metres.

2.6.5 Supply Reliability

Steam Systems

Most steam systems consist of tree branching configurations. Where a high degree of supply reliability is required (such as at hospitals), an extra steam supply pipe may be included as back-up in case of failure. Other approaches to increase system reliability include:

1) Two parallel supply lines

2) Looping the distribution network (instead of branching).

3) Two or more steam plants located at different parts of the system.

Hot Water Systems

Most hot water systems are also tree branching configurations. Options to increase supply reliability include:

1) Installation of peaking and emergency boilers at different parts of the system.

2) Looping the distribution network.

3) Installation of 3 or 4 pipes instead of 2.

4) Segmentation of the system with sectioning valves and the use of mobile emergency boilers to serve sections isolated during a problem.

2.6.6 Temperature

Steam Systems

Because most steam systems operate with saturated steam at 7-14 bar g (100-200 psig), the operating temperatures will be 170-200°C. Temperatures may be slightly lower in the summer when the steam pressure can be reduced because of lower demand and pressure drop in the lines.

Hot Water Systems

The determination of appropriate supply/return temperatures for hot water systems involves consideration of three objectives:

1) High maximum design supply temperatures are desirable in order to maximize delta T, the temperature differential, at the connection, and minimize pipe sizes and costs;

2) Low return temperatures are desirable in order to maximize delta T at the connection, reduce heat losses and maximize utilization of low temperature heat sources;

3) Low average supply temperatures are desirable in order to limit heat losses and increase the utilization and efficiency of low temperature heat sources, such as heat pumps and back pressure turbines.

A typical supply/return temperature program in a hot water

system is 120°C /80°C during the winter and a 75°C supply during the summer (to satisfy DHW demand).

2.6.7 Pressure

Steam Systems

The pressure of the steam system must be sufficient to transport the maximum demand for steam from the boiler plant to the most remote user and to satisfy all temperature requirements. Most steam systems are operated at approximately 2,400-3,600 m/min (8,000-12,000 ft/min) steam velocity. Typical pressures may range from 7 to 14 bar g (100-200 psig).

Hot Water Systems

Hot water systems operating at temperatures higher than 100°C must be pressurized to avoid flashing of steam. Most hot water DH systems are pressurized to 3-4 bar g (45-60 psig). This level of pressure provides for a safety margin as well as differences in elevation between the boiler plant and various points in the system.

The hot water system must also have a differential pressure between the supply and return pipes to establish flow. The pressure differential, or delta P, required over the substation is usually approximately 1 bar. The pipe system is usually designed with a relative pressure drop of 1-2 mbar/m.

Most systems are pressure rated between 10 and 25 bar g (150-360 psig).

2.7 Production Plants

Steam Systems

A steam boiler plant must produce sufficient pressure to transport the steam through the system. When high pressures are needed, high flue gas temperatures (and lower efficiency) may result unless economizers are used. Blow-down of the boilers increases the level of system heat losses. Plant pressures will typically be higher than distribution pressures and a pressure regulating station will be used to control the distribution pressures.

Deaeration and treatment of feedwater is critical to ensure long life and high efficiency of the boiler. Back pressure turbines in boiler plants for steam systems will have a

limited power yield because of the relatively high pressure requirements of the distribution system. Low temperature heat sources can only be utilized for minor applications such as for feedwater preheating.

Hot Water Systems

Heat only boilers for hot water systems are less complex than steam system boilers. With a closed system, water treatment is simplified and there is no requirement for condensate return and feed water tanks and pumps. Flue gases can be cooled to relatively low temperatures without economizers. This advantage can be utilized when burning low-sulphur fuels, such as wood-chips. The flue gases can then be cooled to below 100°C before condensation of vapour takes place. Flue gas condensors have recently become commercially available that substantially increase the efficiency.

Hot water systems also provide good opportunities for cogeneration with back-pressure turbines. Because the steam can be condensed at a low temperature (which is sufficient to meet the thermal requirements of the DH supply), the power yield is relatively high. A recent report by the International Energy Agency (1987) suggests that the increase in electrical output can be as high as 40% compared to a 150 psig steam system.

Thermal storage in the form of large hot water tanks can be utilized at heat only or cogeneration plants for hot water systems to increase the operating flexibility and efficiency of the production plant. Low temperature heat sources (such as industrial waste heat recovery system and large heat pumps) can also be incorporated in the overall configuration of hot water system production plants.

2.8 Maintenance and Operation

Steam Systems

Considerable attention is required to ensure that a steam plant and distribution system are properly operated and maintained. Feedwater must be carefully treated and the condensate monitored. In addition, many mechanical parts in the system, such as steam traps, pumps, tanks, compensators and valves, require periodic maintenance.

Hot Water Systems

The operation of hot water distribution systems is usually fully automatic. The hot water distribution system contains relatively few mechanical parts that require maintenance.

However, the plant must be monitored regularly to ensure optimal efficiency. Water quality must be monitored to ensure a long life for the system. Only limited water treatment will normally be required during operation. Medium/low temperature hot water boiler plants do not always require boiler operators by code when directly connected and rated at 2 bar g (30 psig). Larger plants are usually staffed to increase the availability and efficiency.

2.9 Availability of Technology

Steam Systems

The technology of steam distribution systems is well understood by the Canadian engineering community. Suitable materials and equipment are readily available.

Hot Water Systems

Although widely accepted in Europe, hot water distribution technology has been applied in only a limited number of projects in Canada. Successful demonstration projects have identified sources of material and equipment that are acceptable to local authorities at costs only slightly higher than are found in Europe.

An International Energy Agency report comparing district heating piping among member countries showed that Canadian costs were substantially higher for early projects, such as LeBreton Flats (Ottawa, 1981/82). Costs have been significantly reduced in recent years with experience from the district heating projects on Prince Edward Island. Through these projects, suitable North American and European products have been registered for use in Canadian systems, at prices significantly below those previously experienced in Canadian installations.

3.0 Case Studies

3.1 Introduction to Case Studies

Two district heating systems were selected for case study analysis to compare steam and hot water technologies. The first case study was based on a prospective new district heating system in downtown Charlottetown, Prince Edward Island. Such a system would have approximately 40 subscribers and a total connected load of 12 MW. The second case study was based on the existing steam distribution system at McMaster University in Hamilton, Ontario. At the time of this study, the McMaster system connected 33 campus buildings and a hospital, and had a total load of approximately 33 MW.

While the case studies were based on actual site conditions, simplifying assumptions were required to allow the development of comparative designs. The resulting designs still provide an adequate basis for the comparative analysis presented in this section.

The design parameters are first outlined for each case study. The hot water and steam systems are then described and compared. A discussion of general findings from the two case studies follows in Section 4.

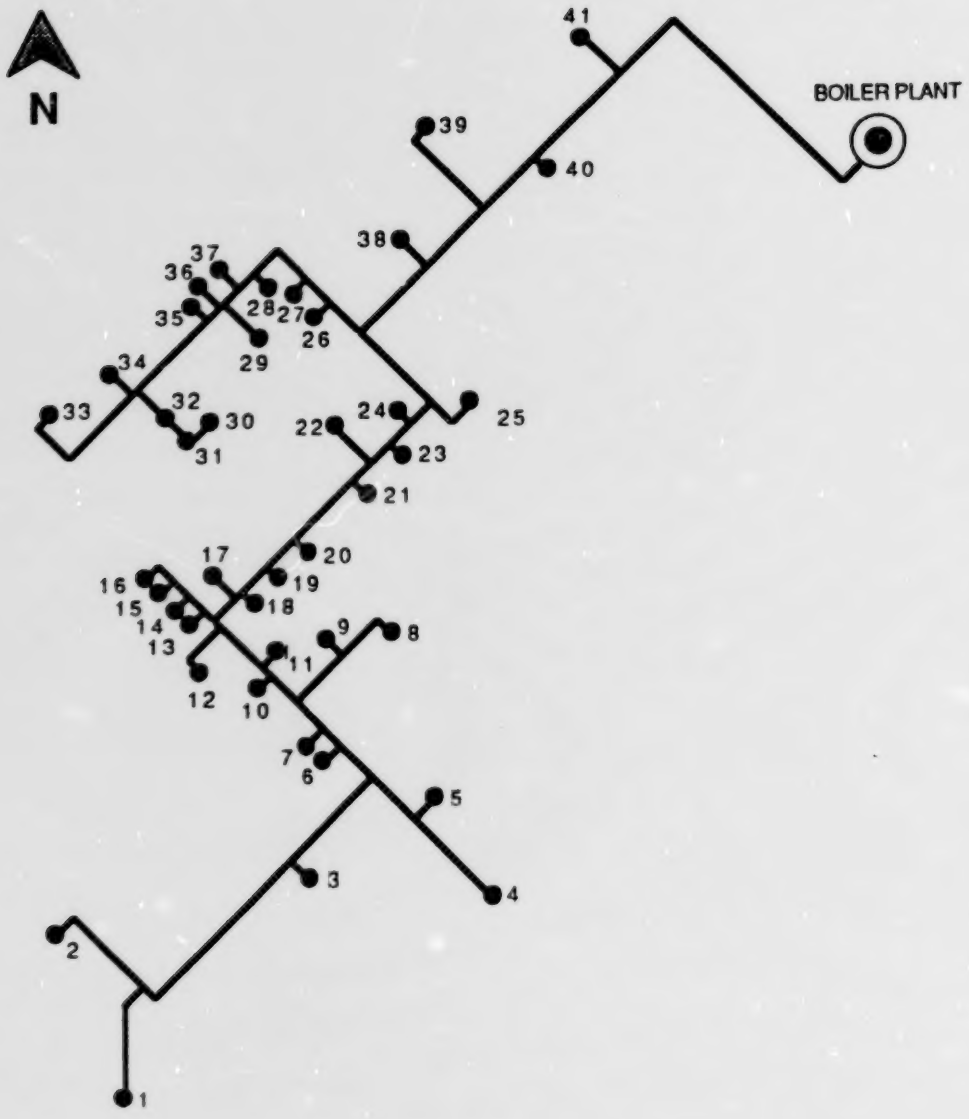
3.2 Charlottetown

3.2.1. Description of Site

Two district heating projects had been developed in Charlottetown, P.E.I. However, neither project incorporated the downtown core. This case study evaluated a distribution system for one of the options being considered for DH development in the downtown area.

The approximate layout for the prospective system is given in Figure 3.1. The proposed system would include 41 customers with individual peak demands of approximately 50-200 Kw and a total connected load of approximately 12 MW. Four of the subscribers were heated by low pressure steam systems. Two of these could be completely converted to hot water and the other two (sites 2 and 39) substantially converted to hot water. Sites 2 and 39 used process steam, one for a kitchen and laundry and the other for laundry only. Conversion costs for the four sites ranged from $10,000 to $100,000. All steam use that could be converted was low pressure steam and none of the sites had absorption chillers. The remaining steam use was at approximately 2-7 bar g (30-100 psig) and

Figure 3.1



Charlottetown
District Heating System
Layout and Subscribers

could no be supplied by the DH system.

The new boiler plant that would supply the energy was assumed to be located adjacent to an existing 30 MW oil-fired standby generating station.

Charlottetown is located on the coast of P.E.I. on rock-free soils which simplifies excavation. However, the fine grade of the sand increases the risk of frost-heaving in the area. This risk can be minimized by using appropriate backfill material and well insulated pipes.

Existing utilities, including water, sewer, electricity, and cable TV (and abandoned gas pipes) were located in the streets. Two district heating projects had recently been built close to the downtown core and installation costs associated with the site could therefore be estimated with accuracy.

3.2.2 Description of Steam Design

Steam with sufficient temperature and pressure could be distributed to the four buildings requiring steam so that conversion would be unnecessary. The remaining buildings would require a substation with a heat exchanger interface to separate the steam DH and hot water building systems.

In order to ensure delivery of steam to all subscribers, 14 bar g (200 psig) saturated steam at 195^{o} C would be produced at and distributed from the plant. The substations would be equipped with a pressure reducing station to reduce the pressure to approximately 0.3 bar g (5 psig) so that the steam would condense in the heat exchanger at temperatures near 100^{o} C. In order to provide adequate comfort levels in the buildings, the substations would be equipped with a mixing valve on the secondary side. DHW would be heated through an existing tank/coil connected on the secondary side (Conversion costs for buildings with separate DHW heating were not included). The condensate would be collected in an open condensate tank (with vent) and pumped back to the boiler plant to save thermal energy and water treatment chemicals. The condensate was assumed to be metered through a condensate flow meter except in the few cases where steam would be consumed without the condensate being returned. In these cases, steam meters would be required.

The piping system would be directly buried, with schedule 40 pipe specified to provide an allowance for corrosion. The installation design consists of standard pipes for steam and condensate pipes, fibreglass insulation, sheet metal jacket, and poured-in-place concrete with bituminous coating. A leak

detection system was not included.

The system would operate at 14 bar g (200 psig) in the winter and at slightly lower temperature and pressure during the summer. The design steam velocity was 3,000 m/min (10,000 ft/min).

Sectioning gate valves would be installed in manholes. Because the valves would not be pre-insulated, manholes complete with bottom and drain were assumed to be installed. The manhole must be large enough to accommodate a maintenance man. Manholes must also be installed in all low points where steam traps and condensate tanks/pumps are required.

The heat losses in the system were estimated to be approximately 3,700 MWh (approximately 15% of delivered energy) plus losses in connection with such factors as maintenance, leakages, and blow-down.

To control pipe stresses, the distribution system was assumed to be of the sliding type with large temperature differences creating a high level of expansion. The expansion requirement would therefore be taken up through the installation of expansion devices. Expansion bellows were assumed to be used in this installation, because they save space and are convenient. A bonded system is only possible if the casing also expands.

A schematic of the substation and a diagram of the piping are provided in Figures 3.2a and 3.2b, respectively. The total investment cost of the distribution system and substations in 1987 $ was estimated at:

Distribution Network (3,866 m)	$2,226,700
Substations (41)	951,200
	$3,177,900

Details of the design assumptions and investment cost estimates are presented in Appendix 3. All materials used in the design were available and approved for use in Canada.

The total system was expected to require maintenance and other operating costs of approximately $110,000/year (2.5% of the capital investment cost plus the salary of one maintenance engineer). The potential lifetime of the system of 30 years would require implementation of high standards for operating and maintenance procedures.

The design of the distribution system would limit the efficiency of the boiler plant. Feedwater and air preheaters

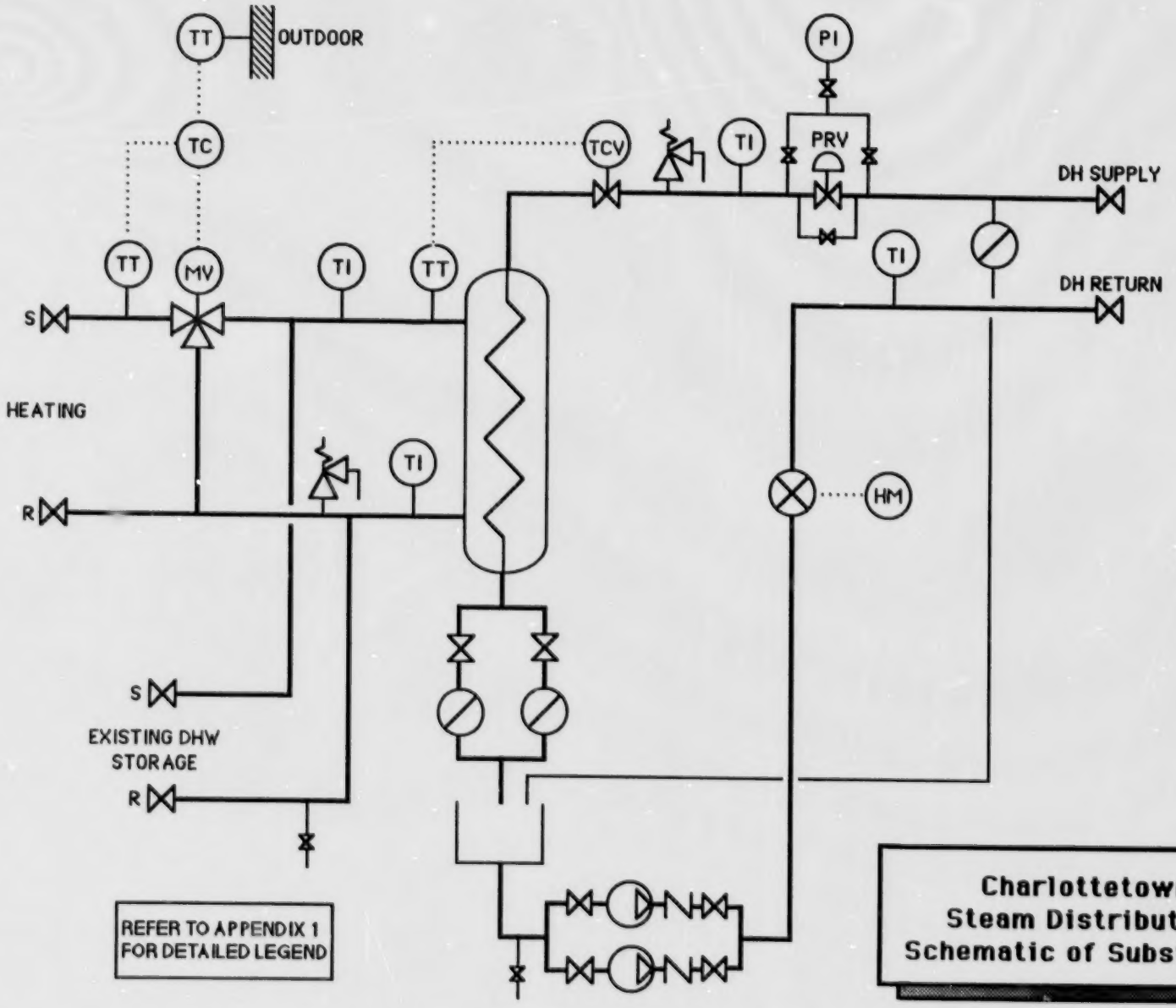
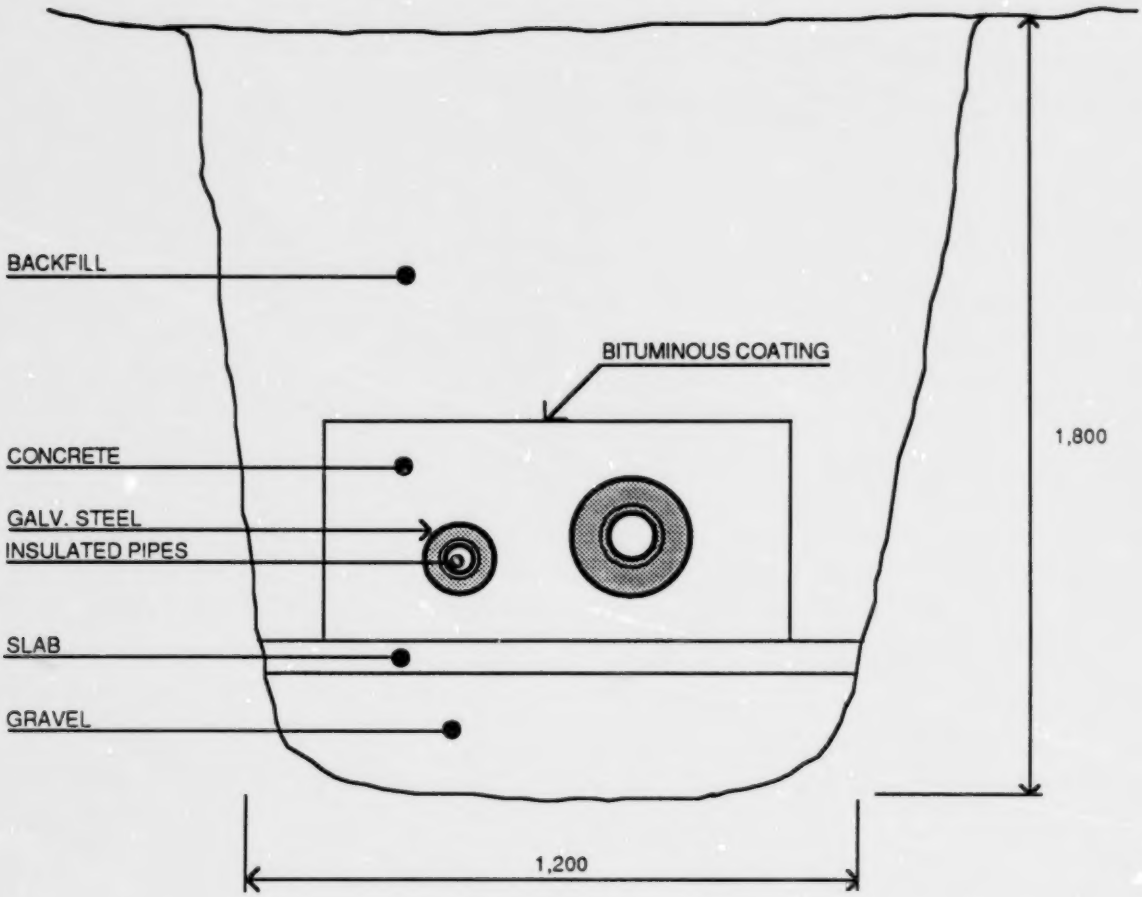


Figure 3.2a

Charlottetown
Steam Distribution
Schematic of Substation

Figure 3.2b



All measures in mm

Charlottetown
Steam Distribution
Cross Section of Trench

must be utilized to increase efficiency. The high steam temperature would decrease power yield in conjunction with cogeneration. The plant would consume chemicals to treat the water to standards sufficient to minimize wear and corrosion.

The system would not need distribution pumps and could serve new absorption chillers which might be installed at individual sites.

3.2.3 Description of Hot Water Design

Almost all subscribers had low temperature hot water systems with maximum operating temperatures of 80-90°C. In order to maximize the amount of energy supplied by the DH system, as much of the low pressure steam demand as possible should be converted. Even though the cost of converting the buildings was high, it was expected to be feasible because no extra network piping would be needed to supply the additional customers. Existing use of process steam was assumed to continue and consequently only parts of these sites would be converted.

Because the building heating systems were expected to operate at approximately 80-90°C at design conditions and the temperature drop under peak conditions would be approximately 10-20°C, the expected average return temperature was 75°C on the secondary side and 80°C on the primary side. A high design supply temperature was preferred so that pipe sizes and capital cost could be minimized.

Preinsulated steel pipes with polyurethane foam and polyethylene casing were selected as the least expensive and most cost effective piping system. The maximum supply temperature was therefore limited to 120°C which resulted in a design temperature drop of 40°C. During the summer, the system would be expected to operate at lower temperatures sufficient to satisfy DHW heating demand. The summer supply temperature would be approximately 65-80°C, depending on the final design of substations.

The pipes were sized with a maximum relative pressure drop of 2 mbar/meter. This pressure drop was a practical limit where noise, erosion and extremely high pump heads could be avoided (under special conditions a higher relative pressure drop could be used). It might also be advisable to decrease the pressure drop (increase the pipe size) if a remote pumping station could be eliminated. Remote pumping stations are expensive to build and require advanced controls when operated in conjunction with other pumps in the system.

The 120°C supply temperature required that the system be

pressurized to avoid flashing of steam. A safety margin plus allowance for changes in elevation was added to the theoretical pressure to prevent flashing of steam. The pressurization pressure of 4 bar g was therefore selected.

Assuming a design differential pressure over the substations, the required pressure head (except boiler plant) was 11.2 bar g and the maximum pressure was 15.2 bar g. The pressure rating of the system was therefore set at 16 bar g. Given the maximum system pressures for this project, "thinwall" pipes could be used for the installation. Thinwall pipes were less expensive than Schedule 40 pipe and required only two weld passes compared with three or four passes required for Schedule 40 pipe in Canada. The pipe system was assumed to be equipped with a standard electronic leak detection system.

Sectioning valves in manholes were included in the piping system design. The valves were assumed to have welded-body welded-ends for welding, offering no leaks and little maintenance, and be preinsulated for low heat loss and direct burial. Each manhole would consist of a Dia 1500 mm concrete circle installed on top of the preinsulated valves/pipes. The manhole would be covered with frame and cover. This type of manhole would be simple and relatively inexpensive. Similar manholes were designed for vents. Drain manholes were designed with bottoms and equipped with preinsulated ball valves, Dia 50-65mm.

The total length of the trenches for the Charlottetown system was 3,866 meters. Using the "plus" insulation level, the heat losses were calculated at 7% or approximately 1700 MW/year. With standard insulation, the heat losses would be approximately 30% higher, or 9%. Minor additional heat losses would be associated with the maintenance of the system and the boiler plant.

The distribution system was assumed to be bonded. Main pipes would be preheated and friction anchored to save expansion offsets and therefore decrease the impact on traffic during construction. Smaller pipes and services would have expansion offsets to allow for cooling or disconnection.

Expansion of the system volume due to temperature changes would be taken up in an expansion vessel, sized to accommodate the ranges in operating temperatures. The effective tank volume would be approximately 3,000 litres (or 2-3% of system volume).

The substations were assumed to be indirectly connected to the distribution system. The substations would be parallel with 2-stage couplings used at sites with extensive DHW use

so that the extra cooling effect could be used. A few sites would have only one heat exchanger. All substations were assumed to be equipped with induction type flow meters with an integration unit for energy calculations. The heat exchangers were assumed to be tube and shell type without gaskets, suitable for district heating. The substation controls were assumed to be electronic, with electric actuators mounted on control valves, suitable for high pressure differentials. The heat exchangers made possible a relatively high design temperature and pressure, desirable for optimal operating performance.

A schematic of the substation and a diagram of the piping are provided in Figures 3.3a and 3.3b, respectively. The total investment cost of the distribution system and the substations in 1987 $ was estimated at:

Distribution Network (3,866 m)	$1,349,600
Substations (41)	1,121,400
	$2,471,000

Details of the design assumptions and investment cost estimates are presented in Appendix 3. All materials used in the design were available and approved for use in Canada.

The distribution system and the substations were estimated to require maintenance and other operating costs of approximately $55,000/year (1% of the investment cost plus the salary for one maintenance engineer). The expected lifetime for the system was estimated to be approximately 30 years.

The design temperature of the distribution system would permit a high boiler plant efficiency, utilization of low temperature heat sources and good potential for cogeneration. The primary fuel for this kind of installation on P.E.I. would be wood chips. Because of the low acidity of the flue gases, the gases could be cooled to below 100°C without major concern for boiler tube corrosion. The total efficiency would therefore be very high. If hot water boilers were used for the boiler plant, the boiler plant cost, as well as the operating and maintenance cost could be minimized.

Water treatment would consist of mechanical filtration, steam deaeration (if steam was available), water softening and pH adjustment. Because a closed loop system was selected, ongoing water treatment requirements would be relatively low.

The distribution pumps would include variable speed drives which would be particularly appropriate due to the high cost of electricity on P.E.I. The stresses on substation

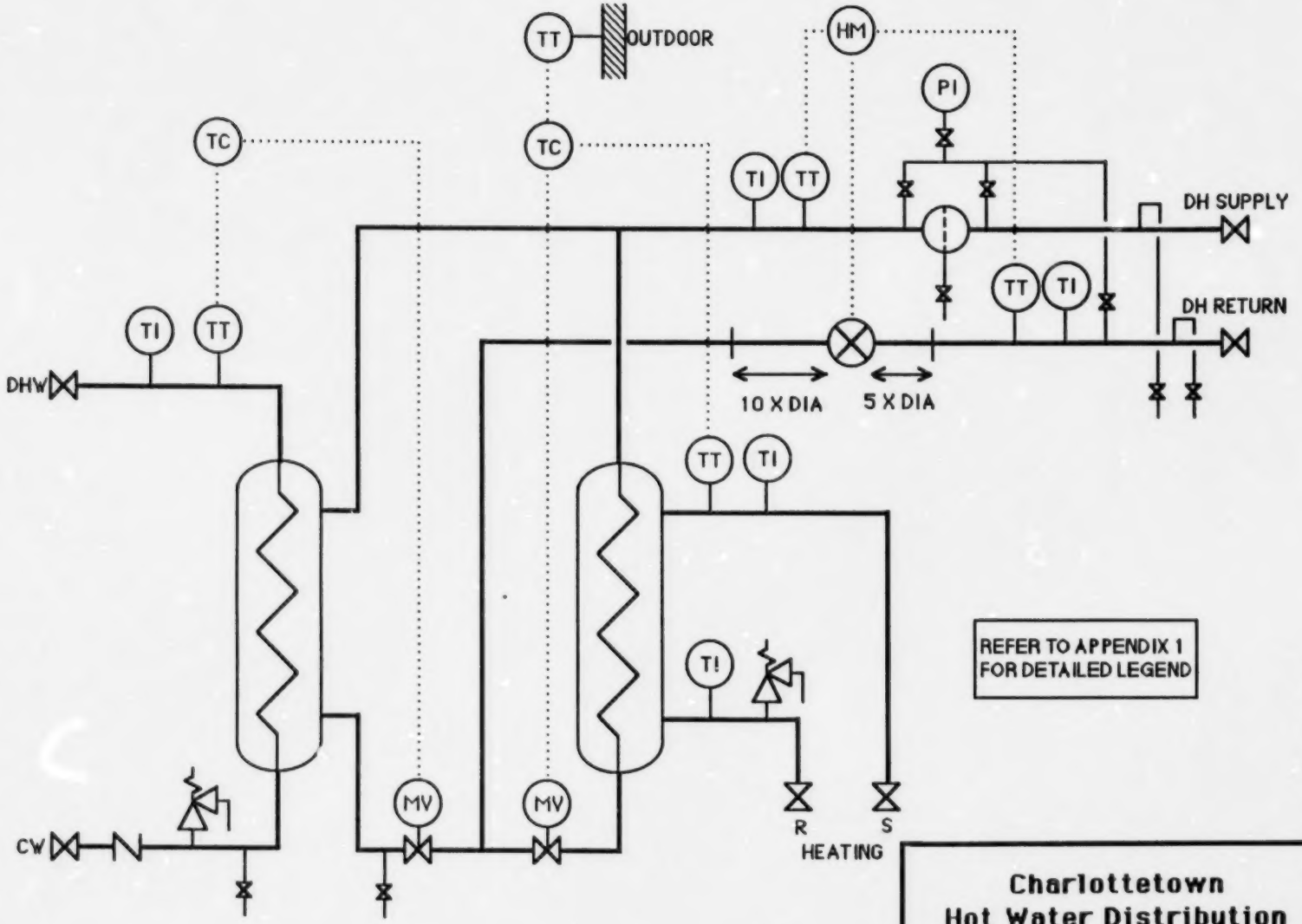
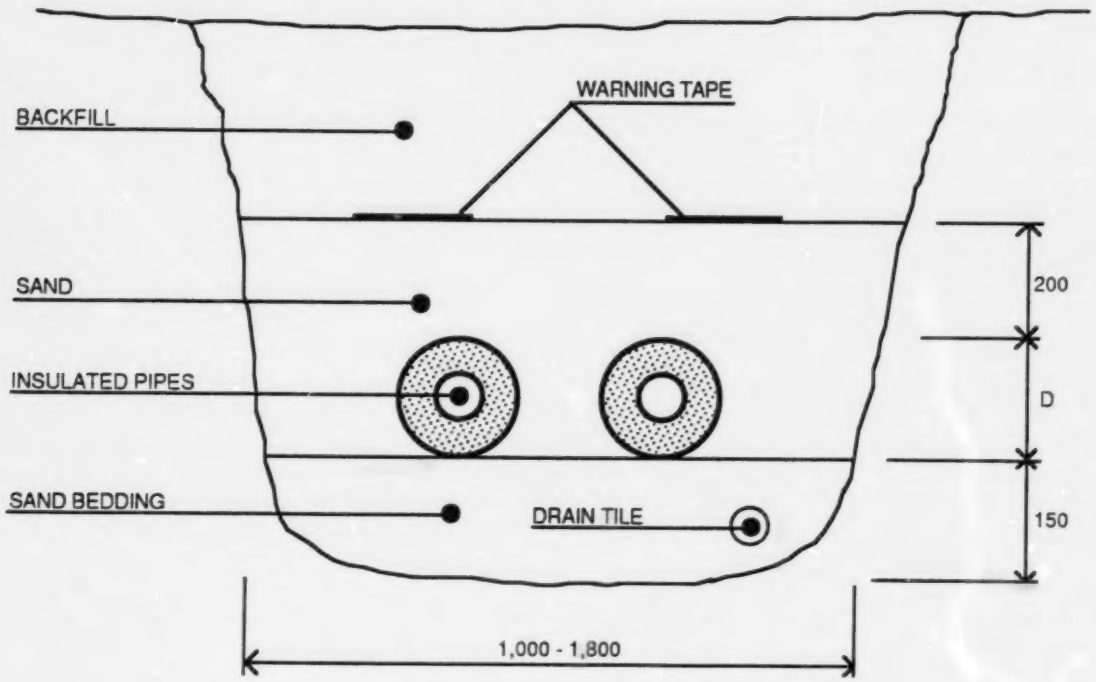


Figure 3.3a

Charlottetown
Hot Water Distribution
Schematic of Substation

Figure 3.3b



All measures in mm

Charlottetown
Hot Water Distribution
Cross Section of Trench

equipment and control valves would also be reduced with the use of variable speed pumps.

3.2.4 Comparison of Steam and Hot Water Distribution

A summary of the comparison between the two preliminary designs for a new downtown Charlottetown system is presented in Table 3.1. Each portion of this comparison is discussed below.

System Configuration

The distribution network was 3,866m in length, with 41 sites connected to the system. The peak load was approximately 12 MW. Annual delivered energy was estimated at 25,000 MWh.

User Requirements

The steam system could meet all existing space heating, DHW and process requirements. For the hot water system, existing steam space heating systems must be converted at four buildings. The cost of conversion was included in the capital cost estimates for the substations. Process requirements for laundry and kitchen uses at two of the sites could not be converted to hot water and must be served by existing steam boilers.

Capital Cost

The capital costs for the distribution network and building substations were estimated to be 29% higher for the steam system than for the hot water system ($3.2 million vs. $2.5 million in 1987 dollars). Figure 3.4 illustrates the component costs for the two proposed systems. Lower piping cost was the major cost advantage of the hot water distribution system.

Heat Loss

The estimated heat losses in the distribution network for the steam system were more than double those for the hot water system (15% of delivered energy compared to 7%). Valued at the cost of wood-chip base-load fuel ($13/MWh including boiler efficiency), these line losses would cost $48,000 annually for the steam system and $22,000 for the hot water system, for a difference of $26,000 per year. Steam system losses would be greater if a rigorous maintenance program was not followed.

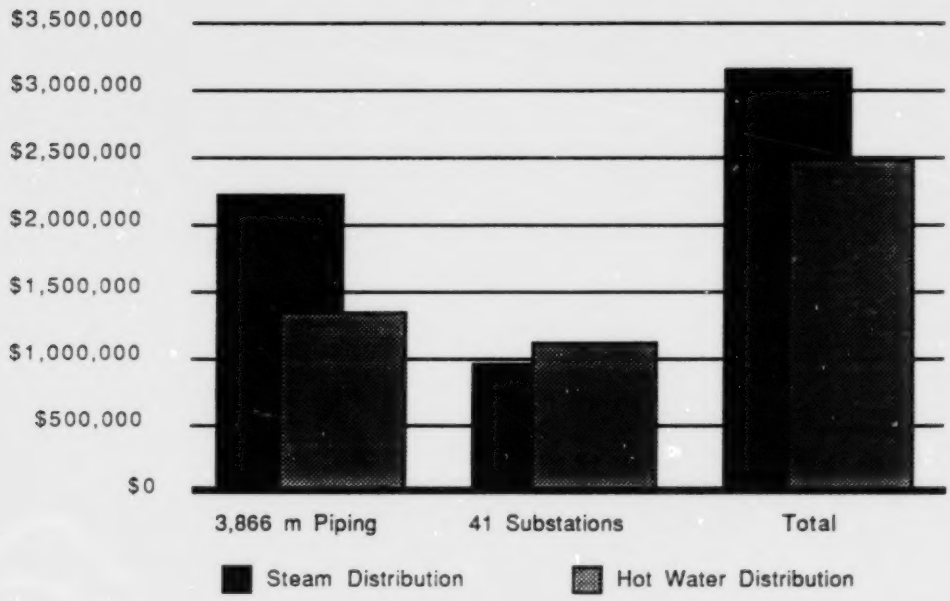
Table 3.1

Summary of Comparison of Steam and Hot Water DH Systems
for New Downtown Charlottetown Systems

System Configuration: 3,866 meters
41 Connected Sites
Peak Load: approximately 12 MW
Delivered Energy: 25,000 MWh

	Steam System	Hot Water System
User Requirements	Meets all space heat, DHW and process needs	Cannot meet process needs at two sites (Existing boilers left to supply steam)
Capital Cost (1987 $)		
Distribution Network	$2,226,700	$1,349,600
Substations	951,200	1,121,400
Total	$3,177,900	$2,471,000
Heat Loss	15% of delivered energy plus leakage ($48,000/yr)	7% of delivered energy ($22,000/yr)
Maintenance and Operating Costs	$110,000/yr (2.5% of capital cost & salary of maintenance engineer)	$55,000/yr (1.0% of capital cost plus salary of maintenance engineer)
Supply Reliability	High	High
Durability	20-30 years (highly dependant on regular maintenance)	30-40 years
Metering	Accuracy +/- 10% Depending on meter and application	Accuracy +/- 2%
Leak Detection	None	Integral electronic system
Cogeneration	Limited opportunity	Well suited
Boiler Plant	High Capital Cost Higher operating costs Less efficient	Lower capital cost Lower operating costs More efficient
Availability of Technology	Proven, widely available	Proven, limited availability in Canada

Figure 3.4



Charlottetown System Comparison of Capital Costs for Steam and Hot Water Distribution Systems

Maintenance and Operating Costs

The maintenance and operating costs for the steam system were estimated to be twice those for a hot water system ($110,000/yr vs. $55,000/yr). The estimates were based on a factor of 2.5% of capital costs annually for the steam system and 1.0% of capital costs annually for the hot water system plus the salary of one maintenance engineer. The difference in costs between the two systems was based mainly on the greater number of mechanical parts requiring attention and the water treatment required in the steam system.

Life Cycle Costs

The combined impact of capital costs, heat losses and maintenance costs is illustrated in the life cycle costing in Table 3.2. The life cycle costs for hot water were potentially 45% lower than for steam.

Table 3.2

Life Cycle Costs for the Charlottetown System

	Steam	Hot Water
Capital Cost	$3,177,900	$2,471,000
Annual Amortization[1]	$ 373,300	$ 290,000
Operating and Maintenance	110,000	55,000
Heat Losses	48,000	22,000
Annual Cost	$ 531,000	$ 367,000

[1] Amortized at 10% for 20 years.

Supply Reliability

Both systems can be expected to provide a high degree of supply reliability.

Durability

Although the longevity of distribution systems cannot be predicted with precision, it was reasonable to expect hot water systems to last longer than steam systems. Experience has shown that steam systems may last 20-30 years and hot water systems 30-40 years. The durability of steam systems is greatly influenced by the level of attention to operating and maintenance requirements in such areas as make-up water

quality and maintenance of mechanical parts.

Metering

The hot water system substations incorporate heat meters with reasonable levels of accuracy (+/- 2%) on which to base monthly billings for delivered energy. The steam system includes expensive, accurate steam flow meters only at the two sites with process requirements. The remaining sites utilize condensate-return flow-meters that would be adequate but less accurate for measuring energy consumption.

Leak Detection

No leak detection system was incorporated in the steam system. The hot water system incorporated an integral, automatic leak detection system which would be triggered by leakage through either the outer casing or carrier pipe.

Cogeneration

The plant providing thermal energy for the steam system would have a limited ability to incorporate cogeneration because a relatively high temperature/pressure supply would be required by the DH network. The hot water system would have a relatively low operating temperature and be well suited for supply from a cogeneration plant.

Boiler Plant

For a new Charlottetown system, the boiler plant to be constructed for a steam system would be more expensive to construct and operate and would be less efficient (without additional economizers and controls) than a thermal plant built to serve a hot water system.

Availability of Technology

At the time of this report, the technology of steam distribution systems was well proven in Canada. Engineering services, materials and equipment required for the implementation of a steam system were widely available. Although widely accepted in Europe, hot water distribution technology had only recently been proven in multiple-building Canadian applications. There was therefore limited familiarity with the technology within the engineering community and a considerable effort would be required to identify cost effective materials and equipment that meet code requirements.

Conclusion

Based on the preliminary designs for a new downtown Charlottetown DH system, it was concluded that the hot water system was preferable on the basis of most technical, economic and operating criteria that were assessed.

3.3 McMaster University

3.3.1 Description of Site

McMaster University in Hamilton, Ontario has an extensive central heating and cooling system. The layout of the system is illustrated in Figure 3.5. The preliminary design work presented in this study describes different options for a replacement of the system, based on the assumption that the existing system was worn out. Only the heating system was evaluated. The cooling system was independent and was assumed to continue to operate without change. The complete distribution system (including the substations) was assumed to require replacement.

At the time of this report, the steam system was generally located in large tunnels (approximately 3x3 m) which were located 3 m underground. Parts of the system were directly buried.

The existing system consisted of a 13 bar g (185 psig) steam pipe and a condensate return. The high pressure steam was reduced in one of the branches. However, for this evaluation, the steam pressure was assumed to be the same in all branches in order to simplify the comparison.

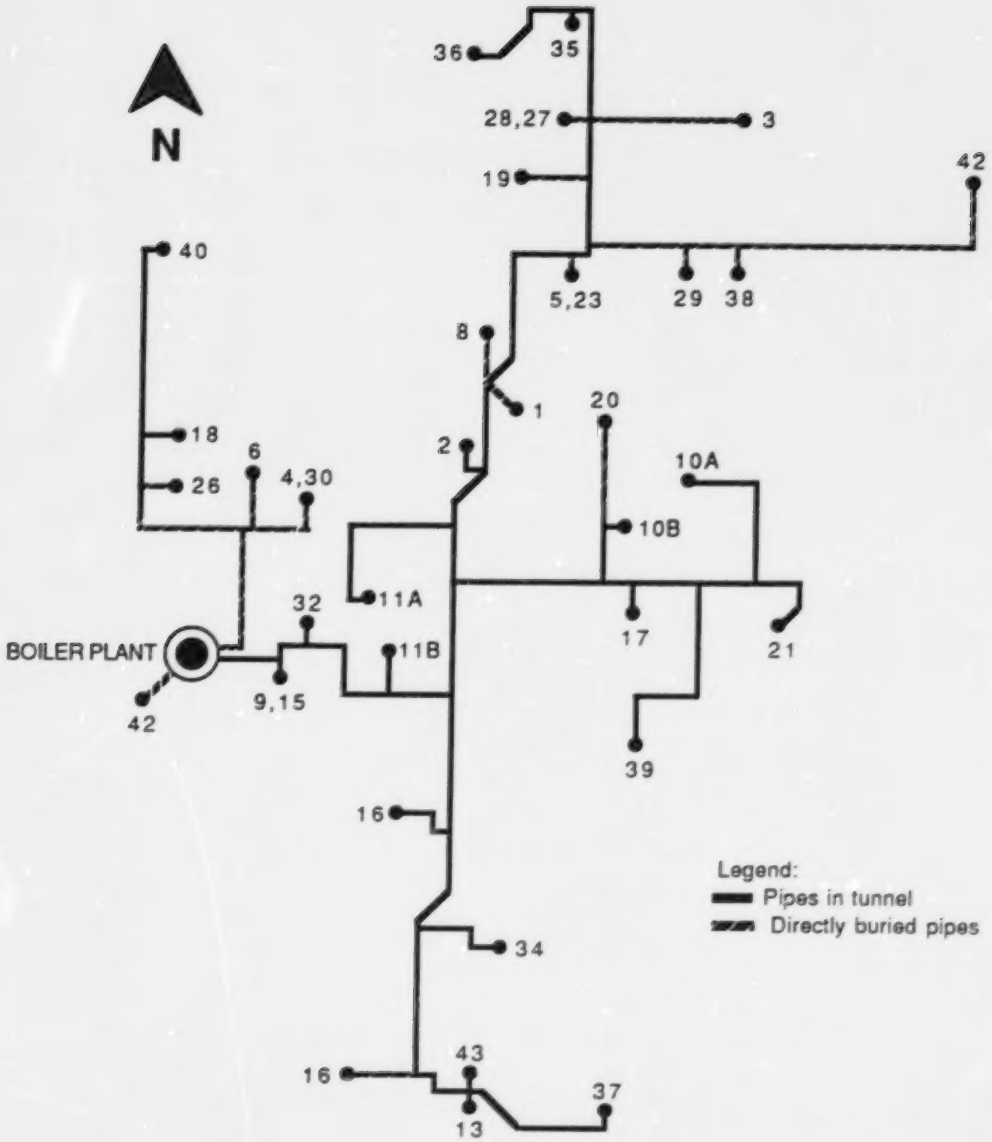
The buildings currently supplied with heat consisted of campus buildings and a hospital. The hospital was not part of the university and the energy consumption was metered and billed. The remaining 33 substations did not have individual metering. Some buildings had two substations, while in other areas one substation served two buildings. To simplify the analysis, the total energy consumption on the campus was divided equally among the buildings to establish an average energy consumption per substation.

The total connected load was 33 MW. Hot water was used in all building secondary systems except within the hospital (approximately 1 MW process steam) and for some steam tables and humidifiers on campus. No sites had absorption chillers. The existing boiler plant that supplied the steam was a natural gas fired thermal plant.

Major problems with traffic during construction and buried utility services in the ground were not expected because the site was a university campus. No rocks were expected when excavating for the pipes. Based on experience in the construction of the existing district heating system, costs associated with the site were reasonably well known.

Because this was a replacement project, the main option was

Figure 3.5



McMaster University
District Heating System
Layout and Subscribers

to replace existing steam and condensate pipes in the tunnel system with new pipes and to build new directly buried pipes where required. If a replacement or conversion were to proceed, existing pipes would be examined for incorporation into the new system wherever possible.

3.3.2 Description of Steam Design

No building conversions were required because steam with sufficient temperature and pressure to meet all requirements was distributed to the buildings. It was assumed that all buildings needed a new substation to replace the heat exchanger interface which separates the steam supply and internal hot water space heat and DHW systems.

In order to ensure delivery of steam to all subscribers, 13 bar g (185 psig) 193°C saturated steam would be produced and distributed from the plant. The substations would be equipped with a pressure reducing station to reduce the pressure to approximately 0.3 bar g (5 psig), so that the steam would condense in the heat exchanger at temperatures near 100°C. In order to provide acceptable levels of comfort in the buildings, the substations would be equipped with a mixing valve on the secondary side. DHW was assumed to be heated through an existing tank/coil, connected on the secondary side. The condensate would be collected in an open condensate tank and pumped back to the boiler plant to save thermal energy and water treatment chemicals. The condensate was assumed to be metered through a condensate flow meter (because of the relatively low cost) except for the hospital, where steam use would be measured by a steam meter.

Where the steam distribution pipe was located in tunnels, it was assumed to be replaced. The old pipes would be removed before the new pipes were installed. Steam service would therefore be interrupted to all buildings except the hospital, where a back-up steam line exists. The piping design inside the tunnel would be standard Schedule 40 pipe with fibreglass insulation and canvas, on supports. Expansion would be taken up through expansion devices such as expansion bellows that would be located in the tunnel.

Where the steam distribution piping was currently directly buried, a similar system would be installed adjacent to the existing lines. The configuration would consist of Schedule 40 steam and condensate pipes, fibreglass insulation, and sheet metal jacket, poured in concrete, coated with bituminous coating. The installation would not include a leak detection system.

The system was assumed to operate at 13 bar g (185 psig) in the winter and at lower temperature and pressure during the

summer. The design steam velocity was 3,000 m/min (10,000 ft/min).

Sectioning gate valves would be installed in the tunnels and in manholes. Because the valves would not be preinsulated, manholes and drains were assumed to be installed. The manhole would be large enough to accommodate a maintenance man. Manholes would also be installed at all low points where steam traps and condensate tanks and pumps were required.

The heat losses in the system were estimated to be approximately 5,000 MWh (approximately 7% of delivered energy) plus losses in connection with maintenance, leakage and blow-down.

The distribution system was assumed to be of the sliding type because large temperature differences cause a high level of expansion. The expansion would be taken up through the installation of expansion devices. Expansion bellows were assumed to be used in this installation because they save space and are convenient. A bonded system would be possible only if the casing expands.

A schematic of the substations and a diagram of the piping are shown in Figures 3.6a and 3.6b, respectively. The total investment cost of the distribution system and substations in 1987 $ was estimated at:

Distribution Network (3,612 m)	$ 1,868,900
Substations (34)	1,548,800
	$ 3,417,700

Details of the design assumptions and investment cost estimates are presented in Appendix 3. All materials used in the design were available and approved for use in Canada.

The total system was expected to require maintenance and operating costs of approximately $115,000/year (2.5% of the investment cost plus the salary of one maintenance engineer).

The design of the distribution system would limit the efficiency of the boiler plant. Feed water and air preheaters must be utilized to increase efficiency. The high steam temperature would decrease the power yield in conjunction with a prospective cogeneration system. The plant would consume water treatment chemicals to meet standards to minimize wear and corrosion. The potential lifetime of the system of 30 years would require implementation of high standards of operating and maintenance procedures. The system would not require distribution pumps.

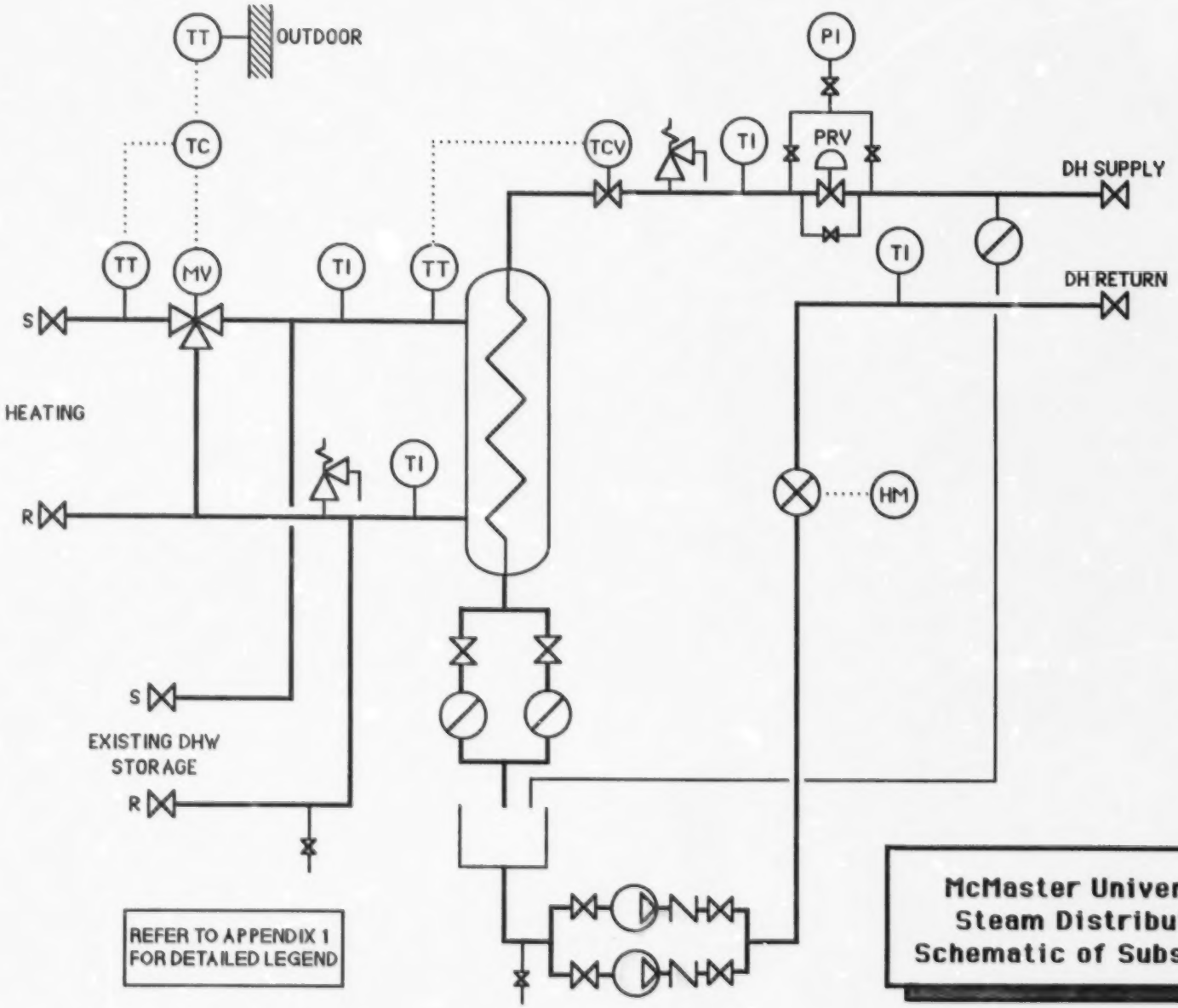
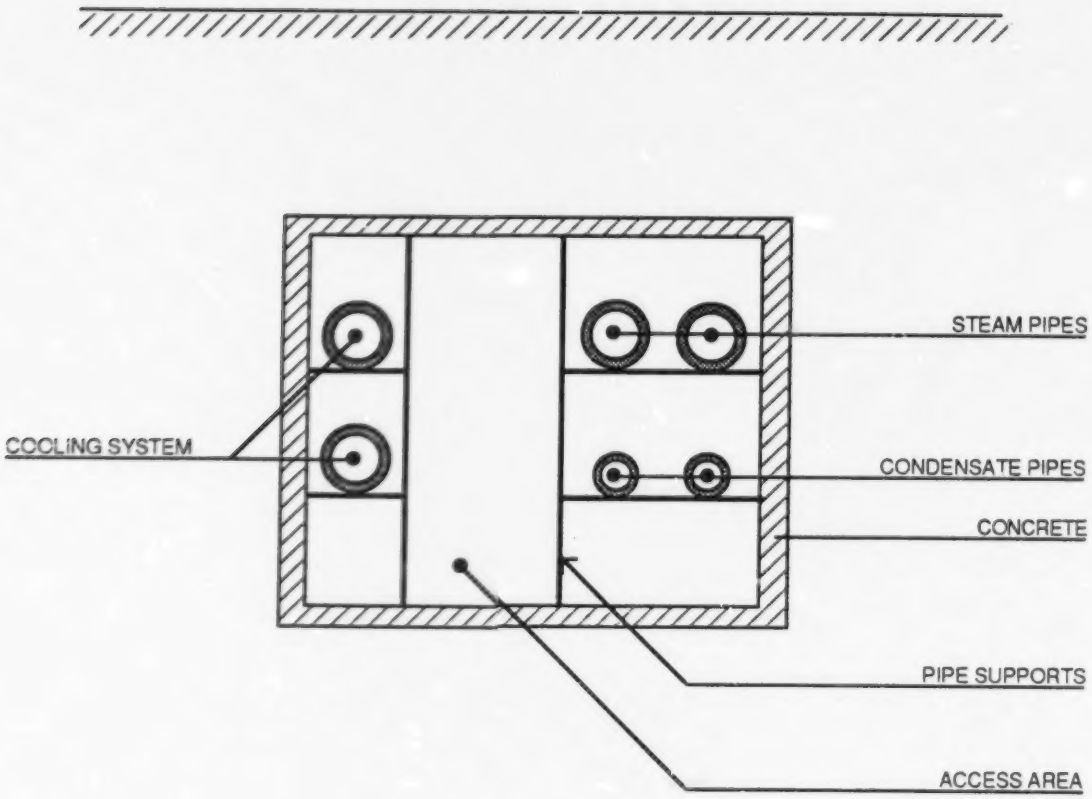


Figure 3.6a

McMaster University
Steam Distribution
Schematic of Substation

Figure 3.6b



McMaster University
Steam Distribution
Cross Section of Main Tunnel

3.3.3 Description of Hot Water Design

Almost all buildings used low temperature hot water systems with maximum operating temperatures of 80-90°C. For the hot water design, it was assumed that existing steam humidifiers on the campus would be changed to hot water humidifiers. Existing steam tables were assumed to be served through the installation of small, separate steam generators (boilers) or the retrofit of the tables, depending on the circumstances. Existing use of process steam in the hospital was assumed to be served through the installation of a small boiler.

Because the heating systems in the buildings were expected to operate at approximately 80-90°C at design conditions and the experienced temperature drop under peak conditions would be approximately 10-20°C, the expected average return temperature was 75°C on the secondary side and 80°C on the primary side.

The cost to install a hot water piping network within the existing tunnels would be very high because the tunnels were crowded and supply and return hot water pipes would be larger than steam and condensate pipes. The system replacement option for a hot water design that was investigated in detail provided for a new directly-buried distribution system adjacent to the existing system.

A high design-supply-temperature was selected to minimize pipe size and capital cost. The least expensive and most cost-effective system for this kind of piping was preinsulated steel pipe with polyurethane foam and polyethylene casing. Using this material, the maximum supply temperature was limited to 120°C with a resulting design temperature drop of 40°C. During the summer, the system would operate at lower temperatures, sufficient to satisfy DHW heating demand. This temperature would be from 65°C to 80°C depending on the final design of substations.

The pipes were sized with a maximum relative pressure drop of 2 mbar/meter. This pressure drop was a practical limit, where noise and erosion as well as extremely high pump heads could be avoided. Under special conditions, a higher relative pressure drop can be used.

The system must be pressurized to avoid flashing of steam because of the 120°C temperatures. A safety margin plus allowance for changes in elevation was added to the theoretical pressure to prevent flashing of steam. A pressurization pressure of 4 bar g was therefore selected. Assuming a design differential pressure over the substations, the required pressure head (except boiler plant) was 3.5 bar g and the maximum pressure 7.5 bar g . The pressure rating

of the system was set at 16 bar g which meant that "thinwall" pipes could be selected for the installation. Thinwall pipes were less expensive than Schedule 40 pipe and required only two weld passes compared with three or four passes for Schedule 40 pipe. The pipe system was assumed to be equipped with a standard electronic leak detection system.

Valves in manholes would be installed in the piping system. The valves were assumed to be welded-end/welded-body valves which would be preinsulated (for low heat losses) and should result in no leaks and low maintenance. The manhole would consist of a Dia 1500 mm concrete circle installed on top of the preinsulated valves/pipes and covered with a frame and cover. Similar manholes would be used for vents. Drain manholes would be equipped with preinsulated ball valves, Dia 50-65mm. This simple manhole design was relatively inexpensive.

The total length of the piping network in the McMaster system was 3,612 meters. Using "plus" insulation, the heat losses were estimated at 3% of delivered energy or approximately 2,200 MWh/year. With standard insulation, the heat losses would be approximately 30% higher, or 4% of delivered energy. Additional minor heat losses would be expected in connection with drain manholes and maintenance on the system and in the boiler plant.

The distribution system was assumed to be bonded. Main pipes would be preheated and friction anchored to save expansion offsets and reduce investment cost. Smaller pipes and services would have expansion offsets to allow cooling or disconnection.

Expansion of the system volume as temperatures change would be taken up in an expansion vessel sized to accommodate the range in operating temperatures. The volume of the tank would be approximately 3,000 litres (2-3% of system volume).

The substations were assumed to be indirectly connected to the distribution system. The substations at most sites would be parallel with 2-stage couplings. The extra cooling effect of the second heat exchanger could be utilized with both space heating and DHW requirements. A few substations would consist of only one heat exchanger. All substations would be equipped with induction type flow meters with an integration unit for energy calculations. The heat exchangers were assumed to be electronically controlled, with electronic actuators mounted on control valves, suitable for high pressure differentials. The heat exchangers make possible a relatively high design temperature and pressure, desirable for optimal operating performance.

A schematic for the substations and a diagram of the piping are given in Figures 3.7a and 3.7b, respectively. The total investment cost of the distribution system and the substations in 1987 $ was estimated at:

Distribution Network (3,612 m)	$ 1,429,700
Substations (34)	1,648,800
	$ 3,078,500

Details of the design assumptions and investment cost estimates are presented in Appendix 3. All materials used in the design were currently available and approved for use in Canada.

The distribution system and the substations were expected to require maintenance and other operating costs of approximately $60,000/year or 1.0% of the investment cost plus the salary of 1 maintenance engineer.

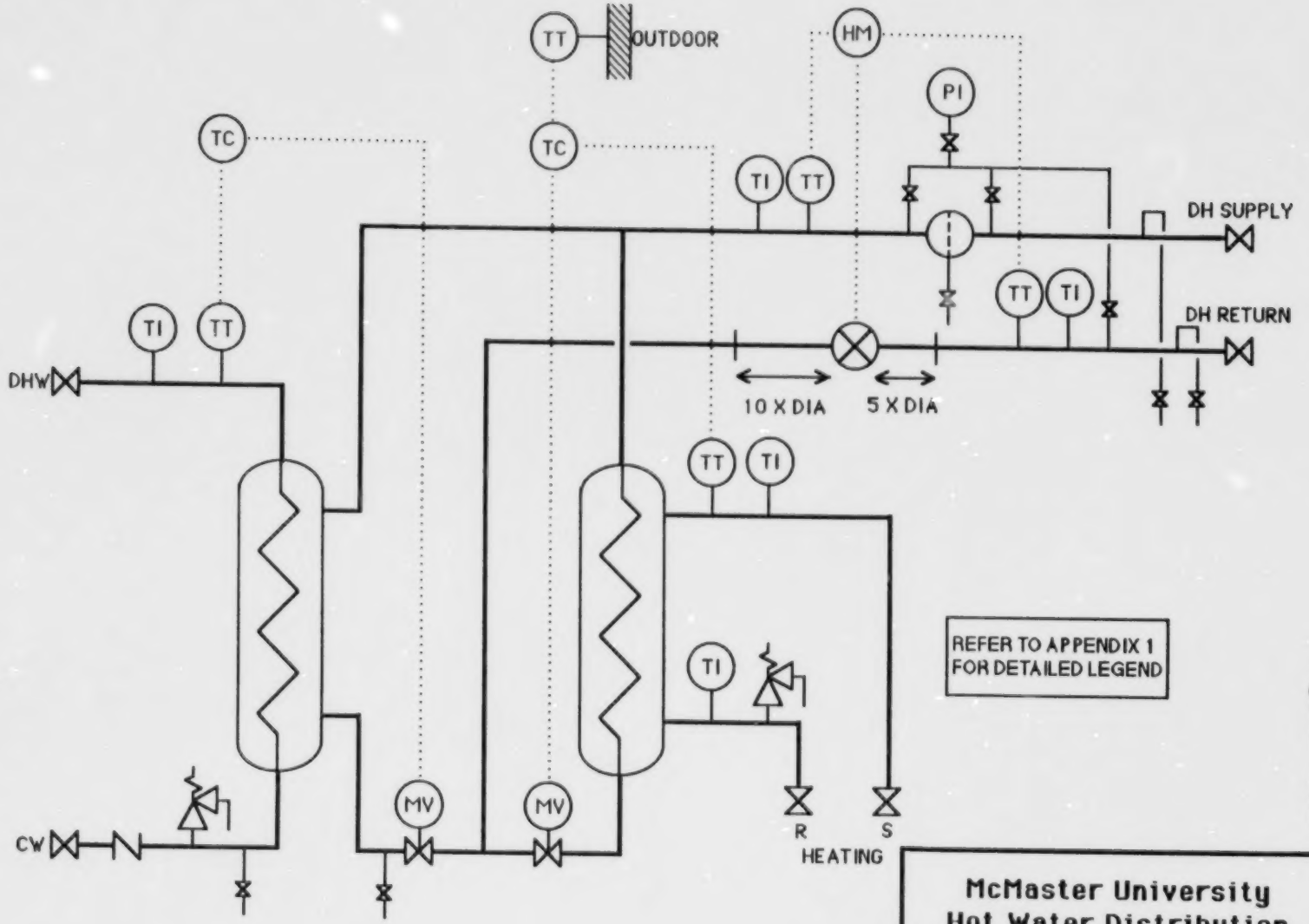
Water treatment would consist of mechanical filtering, steam deaeration, water softening and pH adjustment. Because a closed loop system was selected, ongoing water treatment requirements would be relatively low. The system was estimated to have a life of approximately 30 years.

The design of the distribution system made possible a high boiler plant efficiency and utilization of low temperature heat sources. It would also be suitable for cogeneration. Because the existing plant was gas fired, the flue gases would contain little sulphur and could be cooled to below 100^{o}C. As a result the total efficiency of the boiler plant would be very high.

A steam to hot water heat exchanger, distribution pumps and miscellaneous other equipment, would be required in the existing boiler plant. The total installed cost for this equipment was estimated at approximately $600,000, depending on specific site requirements. The distribution pumps were assumed to include variable speed drives because of the high power saving and reduced stresses on substation equipment.

3.3.4 Comparison of Steam and Hot water Distribution

Table 3.3 presents a summary of the comparison of the two preliminary designs for a hypothetical retrofit project of the entire McMaster University steam distribution system. Each portion of this comparison is discussed below.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FOR DETAILED LEGEND
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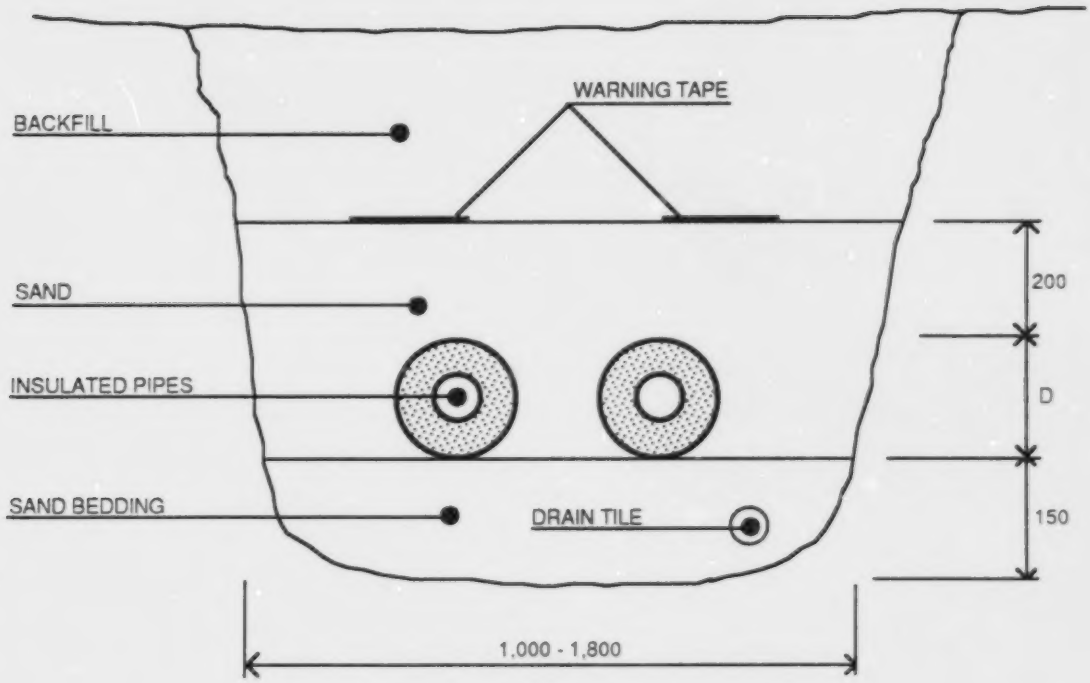
HEATING
McMaster University
Hot Water Distribution
Schematic of Substation

Figure 3.7a

Figure 3.7b



All measures in mm

McMaster University
Hot Water Distribution
Cross Section of Trench

Table 3.3

Summary of Comparison of Steam and Hot water DH System for McMaster University Retrofit System

System Configuration: 3,612 meters
43 Connected Sites
Peak Load: approximately 33 MW
Delivered Energy: 72,000 MWh

	Steam System	Hot Water System
User Requirements	Meets all space heat, DHW and process needs	Cannot meet steam demands at Hospital and steam tables at campus directly.
Capital Cost (1987 $)		
Distribution Network	$1,868,900	$1,429,700
Substations	1,548,800	1,648,800
Total	$3,417,700	$3,078,500
Heat Loss	7% of delivered energy plus leakage ($100,000+/year)	3% of delivered energy ($44,000/year)
Maintenance and Operating Costs	$115,000 (2.5% of capital cost & salary of maintenance engineer)	$60,000 (1.0% of capital cost plus salary of maintenance engineer)
Supply Reliability	High	High
Durability	20-30 years (highly dependant on regular maintenance)	30-40 years
Metering	Accuracy +/- 10% Depending on meter and application	Accuracy +/- 2%
Leak Detection	None	Integral electronic system
Cogeneration	Limited opportunity	Well suited
Boiler Plant	Existing plant is satisfactory	$600,000 required for steam/hot water conversion. Heat exchangers, pumps, etc. included
Availability of Technology	Proven, widely available	Proven, limited availability

System Configuration

The McMaster University DH systems consisted of 34 sites (33 campus buildings and a hospital) connected through a 3,612 meter distribution network. The peak load was approximately 33 MW and the annual delivered energy was 72,000 MWh.

User Requirements

The proposed replacement of the existing steam distribution system would continue to meet all current space heating, DHW, sterilization and steam table needs. The hot water system would require a 1 MW steam boiler for the hospital which was included in the capital cost estimate.

Capital Cost

Assuming replacement of all piping and substations in the existing system, the hot water option would have a capital cost 10% lower than the steam option ($3.1 million vs. $3.4 million). If the $600,000 cost to convert the boiler plant to serve a hot water system was included, the investment cost of the hot water option would be 8% ($261,000) higher. However, operating efficiency could also be increased. Figure 3.8 illustrates the component costs for the two proposed systems. The cost differences for the steam and hot water systems are not large.

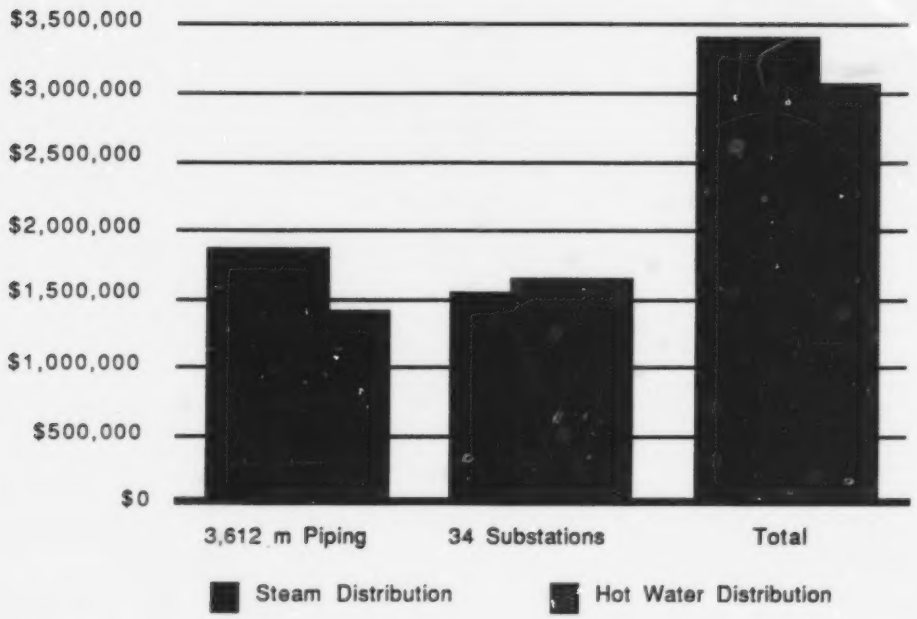
Heat Loss

The estimated system heat losses for the steam system were more than twice those for the hot water system (7% vs. 3% of delivered energy. At a fuel cost of $20/MWh (after including boiler efficiency), the losses translated into annual costs of $100,000 and $44,000, respectively. Steam system losses would be greater if a vigorous maintenance program was not followed. Note that the estimated system losses were approximately half those of the Charlottetown system because almost 3 times (72,000 vs. 25,000 MWh) the energy would be delivered through approximately the same length of pipe (3,612 vs. 3,866).

Maintenance and Operating Costs

The steam system was estimated to incur twice the annual level of maintenance and operating costs of the hot water system ($115,000 vs. $60,000). The estimate for the steam and hot water systems were based on 2.5% and 1.0% of capital cost, respectively, plus the salary of one maintenance engineer.

Figure 3.8



McMaster University System Comparison of Capital Costs for Steam and Hot Water Distribution Systems

Life Cycle Costs

The life cycle costs for the two systems are illustrated in Table 3.4. The life cycle costs were 16% higher for the steam than for hot water.

Table 3.4

Life Cycle Costs for the McMaster System

	Steam	Hot Water
Capital Cost	$3,417,700	$3,048,500
Boiler plant Modification	-	600,000
Annual Amortization[1]		
- System	$ 401,000	$ 358,000
- Boiler plant	-	70,000
Operation and Maintenance	115,000	60,000
Heat Losses	100,000	44,000
Annual Cost	$ 616,000	$ 532,000

[1] Amortized at 10% for 20 years.

Supply Reliability

Both systems were expected to provide dependable supply of thermal energy to the connected sites.

Durability

Based on experience, it was expected that hot water systems would last longer than steam systems (30-40 years vs. 20-30 years).

Metering

With the hot water system, heat meters could be used to monitor all campus buildings (to help identify possible conservation measures) and to facilitate accurate billings to the hospital. With the steam system, less accurate condensate flow meters would provide indications of the level of thermal energy use for individual campus buildings. A steam meter would measure steam delivered to the hospital.

Leak Detection

The hot water system incorporates an electronic leak detection system while the steam system would not have a leak detection system because the high cost would not be justified.

Cogeneration

The steam plant which would supply the steam distribution option would provide limited potential for cogeneration. A hot water option would greatly enhance the potential attractiveness of a cogeneration plant. A back-pressure turbine for hot water district heating would yield 2-4 MWe during most of the year.

Boiler Plant

The existing boiler plant could be used for the steam system option. Approximately $600,000 in modifications would be required to convert the plant to serve a hot water system. However, the plant could be expected to operate more efficiently when providing thermal energy to a hot water distribution system.

Availability of Technology

The technology of steam distribution systems was well proven in Canada. Engineering services, materials and equipment required for the implementation of steam system were widely available. Although widely accepted in Europe, hot water distribution technology had only recently been proven in multi-building Canadian operations. There was therefore limited familiarity with the technology within the engineering community. Effort would be required to identify cost-effective materials and equipment that meet code requirements.

Conclusion

Based on the discussion of the options for replacement of the McMaster University DH system, it was concluded that:

1) The steam options would have a slightly lower capital cost when boiler plant modifications needed for the hot water system were taken into account;

2) The hot water option would provide for significantly greater efficiency and lower operating costs as well as opportunities for increased efficiency and cogeneration at the boiler

plant.

3.4 Impact of Using Low Temperature Hot Water

One alternative for both the McMaster and Charlottetown systems would be to use a low-temperature distribution system so that low-temperature heat sources could be utilized. The overall impact of reducing the design temperature would be:

1) Piping costs would be increased by approximately $370,000 in Charlottetown and $450,000 at McMaster to accomodate the increased flows required;

2) Direct connection would be impractical for both sites because of the large distribution systems and the risks associated with the internal building systems, especially the independently maintained systems in Charlottetown. Substation costs would therefore increase approximately $670,000 in Charlottetown and $860,000 at McMaster;

3) No significant change would be expected in heat losses. The reduction in losses from lower operating temperatures during the winter would be offset by the larger pipe sizes;

4) The use of lower operating temperatures can increase flexibility in piping materials, such as fibreglass. Fibreglass pipe can result in significant savings when compared with Schedule 40 pipe. However, the price differential is not significant if thinwall carbon steel pipe can be used;

5) If cogeneration turbines are used to supply energy, power output can be increased during the winter months. The overall impact would depend on the design and performance of the power plant, the distribution system and the end-user systems;

6) The use of low-temperature distribution systems also offers increased utilization of low-temperature heat sources during the winter months. Sources such as industrial waste heat and heat pumps are generally designed as based-load plants which supply 30-50% of peak heating requirements. In systems such as McMaster and Charlottetown, the supply temperature to both low and medium temperature systems would be comparable during the spring, summer and fall, while peaking boilers based on fuels such as oil would be required for

peaking during the winter months. Overall utilization of low-temperature heat sources would therefore be only marginally improved by the reduction in distribution system temperatures.

The levelized cost of low-temperature systems is compared with the medium temperature systems in Table 3.5. The levelized cost of the low-temperature system was estimated to be 33% and 29% higher than the cost of the medium temperature system for Charlottetown and McMaster, respectively. The investment costs for low-temperature systems would be lower where direct connection is practical. However, this would normally only be feasible for much smaller systems.

Table 3.5

Levelized Cost of Low-Temperature and Medium Temperature Systems

	Charlottetown		McMaster	
	Low-Temp.	Med-Temp.	Low-Temp.	Med-Temp.
	(000)			
Capital Cost	$3,511	$2,471	$4,958	$3,648
Annual Amortization[1]	$ 412	$ 290	$ 582	$ 428
Operating and Maintenance	55	55	60	60
Heat Losses	22	22	36	36
Annual cost	$ 489	$ 367	$ 678	$ 524

[1] Amortized at 10% for 20 years.

4.0 Overall Conclusions

Differences in design approaches for steam and hot water distribution systems were discussed fully in Section 2. In Section 3, preliminary designs were developed and compared for steam and hot water options for a new DH system and the replacement of an existing steam distribution system. In this section, overall conclusions are presented as to the relative merits and limitations of steam and hot water systems.

Planning

At the planning stages for a project, the hot water option offered more opportunities for optimizing the energy management situation because:

1) Cogeneration could be actively considered;

2) Available low grade thermal energy from heat recovery or other sources could easily be incorporated within the system design.

The lack of widespread experience with hot water systems may result in the full potential of a prospective hot water system being inadequately assessed. As with any energy management technology, it is essential that experienced, qualified engineers guide the feasibility and design stages of project development.

Implementation

Hot water was expected to be the lowest capital cost option for construction of many if not most new DH systems. The piping networks for hot water compared to steam systems were considerably less expensive (39% less in the Charlottetown design) while the substation costs were comparable for steam and hot water. Conversion of low pressure steam systems to hot water increased the total connection (substation) cost for the hot water alternative.

For system replacement or conversion projects, it was more difficult to generalize as to which option would likely have the lower capital cost. Principle factors that would determine the total capital cost include:

1) Configuration and condition of the current distribution system.

2) Potential for connecting additional sites to the system.

3) Condition and efficiency of the existing boiler plant.

4) Potential for cogeneration.

5) Potential for adding a new alternative-energy fuelled boiler plant.

6) Potential for utilizing waste heat or other sources of low grade energy.

7) Requirements to convert existing building space heating systems to hot water.

Each potential site must be evaluated independently.

Operation

Hot water systems will be less costly to operate than steam systems because of the following factors:

1) The boiler plant efficiency can be higher;

2) The heat losses in the distribution network are significantly lower;

3) Operating costs for such items as water treatment are significantly lower; and

4) Maintenance, material and repair costs are lower.

Hot water systems may also have a longer life than steam systems, before requiring replacement or major retrofit.

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APPENDIX 1

GLOSSARY OF TERMS

APPENDIX 1
Glossary of Terms

Note: The following terms are defined in their application to district heating systems.

Base Load

The base energy demand of the system usually 20-50% of peak energy demands.

Blow Down

The draining of water from a steam boiler's steam drain and mud drum (or equivalent) on a regular basis.

Box Conduit System

A buried concrete box system containing distribution piping.

Cogeneration

The combined production of both electricity and thermal energy (in the form of steam or hot water).

Condensate Return System

A system that returns the condensate in a steam distribution system from the user to the plant.

Direct Buried System

Distribution piping that is buried in the ground rather than placed in tunnels or conduits.

Direct Connection

Linkage of a user's internal system to a thermal distribution system so that the distribution medium flows directly through the internal system without intermediate heat exchangers.

District Heating System

A heating system supplying two or more buildings with thermal energy.

Delta P

The pressure differential between two distribution points.

Delta T

The temperature differential between two distribution points; typically, the supply and return lines at a substation.

Heat Loss

The loss of thermal energy to the environment surrounding the piping network.

Heat Meter

A device that calculates the quantity of energy delivered based on measurement of flow rates and the temperature differential between supply and return lines.

High Temperature Hot Water System

Hot water distribution system with a peak supply temperature exceeding 120°C, typically 200°C to 250°C.

Leak Detection System

A system that detects leaks in the distribution carrier piping or outer casing that protects the insulation.

Load Duration Curve

A graph illustrating the number of hours per year for which varying thermal energy requirements are registered.

Low/High Pressure Steam System

Thermal distribution systems in which the steam pressure is less than or exceeds 2 bar g (30 psig) (can vary by province).

Low Temperature Hot Water System

Hot water distribution system with a peak supply temperature of less than 100°C.

Medium Temperature Hot Water System

Hot water system with a peak supply temperature in the range of 100-120°C.

Peak Load (Peak Demand)

The maximum energy demand over the year.

Preinsulated Pipes

Carrier piping that has had insulation and an outer casing attached at a factory.

Pressure Gradient

Usually referred to as the ratio of the relative pressure drop per unit length in the pipes between different points in the system.

Substation

Connection between the user and distribution system. A direct connection typically consists of controls, pressure reduction and mixing equipment and a heat meter. An indirect connection typically consists of one or more heat exchangers, valves and a control system and a heat meter.

Thermal Storage

Storage of thermal energy usually in hot water tanks.

APPENDIX 1
DETAILED LEGEND

GATEVALVE

RELIEF VALVE

CHECK VALVE

CONTROL VALVE

STRAINER

PUMP

PRESSURE INDICATOR

TEMPERATURE INDICATOR

TEMPERATURE TRANSMITTER

PRESSURE TRANSMITTER

HEAT METER

MV MOTORIZED VALVE

TCV TEMPERATURE CONTROLLER/VALVE

TC TEMPERATURE CONTROLLER

FLOW METER

PRV PRESSURE REDUCING VALVE

STEAM TRAP

APPENDIX 2

Design Principles of Steam and Hot Water Distribution Systems

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APPENDIX 2
Design Principles of Steam and Hot Water Distribution Systems

This appendix presents an overview of design principles for steam and hot water thermal energy distribution systems. It includes a discussion of the major considerations involved in the design process for new or replacement projects. It must be stressed that the overview is not intended to be an exhaustive discussion of design principles. Such a discussion would have to be much more comprehensive in scope in order to treat the wide range of site specific circumstances that influence an actual design activity.

1.0 Design Principles of Steam Distribution Systems

1.1 Steam Distribution System Alternatives

Although the technology of steam distribution systems for district heating is well established, the application of the basic steam distribution principles varies from system to system depending on the specific application.

Steam district heating systems are used primarily for the same applications as hot water district heating systems. These are:

1) Space heating (either steam or hot water);
2) Domestic hot water heating;
3) Process applications (either steam or hot water).

Low pressure steam (up to approximately 2 bar g or 30 psig) is normally used in small systems connecting only a few buildings. In such systems low pressure steam may be adequate to heat all buildings without excessive condensation and can facilitate the direct use of steam for the distribution systems within the buildings.

Most steam distribution systems and industrial applications operate at 7-14 bar g (100-200 psig) and temperatures between 170 and 200°C (saturated steam). These systems are usually built in box conduits or tunnels, although the service connections may be directly buried. Directly buried pipes often have corrosion problems because of inadequate water treatment and insufficient protection for the thermal insulation surrounding the carrier pipes. Although most systems have been built with condensate return, many return lines have corroded and been abandoned.

Steam systems can also be used as the energy source for absorption chiller systems used for cooling applications, for direct humidification and for sterilization.

Any thermal distribution system serving more than one end-user can be classified as a district heating (DH) system. The steam distribution systems found in almost all process industrial plants would therefore be classified as DH systems. In these systems, steam is normally distributed at medium or high pressure for process use. For heating applications, the steam pressure may be reduced and the reduced pressure steam used as the heat transport medium. Converters or heat exchangers are then used to transfer the thermal energy for the facility's space heating requirements. In some instances, the condensate from the high pressure steam system is allowed to flash to a lower pressure in flash tanks and the lower pressure steam supplements the low pressure steam requirements of the overall system.

Before the sharp increase in the cost of energy in the 1970's, return of condensate in many steam systems was not considered necessary. In recent years, with the increased cost of fuel, it has been recognized that the heat energy in the condensate is significant and well maintained condensate lines should be an integral part of any steam DH system.

1.2 User Requirements

The basic function of a steam district heating system is to deliver a usable form of heat energy to an end user at a temperature and pressure which will satisfy the user's heat demands. Prior to any steam distribution system being designed, the user's requirements must be identified and quantified. Average, maximum and minimum heat requirements as well as pressure and temperature requirements must be known to ensure adequacy of DH system design parameters. These parameters play a critical role in both the selection of the steam generation equipment and the sizing, location and routing of the distribution piping.

Most non-residential buildings in Canada (except industrial) are heated with hot water. However, a large number of older buildings are heated with low pressure steam. In some areas, many buildings are heated with electric resistance heaters, which are costly to convert to steam or hot water in order to connect them to a district heating system.

Most space heating systems using baseboard radiation utilize hot water. Where steam is available, it is often used for special applications such as steam humidification, steam tables in kitchens, sterilization equipment and heating coils for ventilation.

Hot water or low pressure steam systems are used for almost all space heating systems. The temperature and pressure

requirements for these systems are less than the temperature and pressure levels of the most common steam distribution system configuration, 7-14 bar g (100-200 psig saturated steam). The design criteria for the steam distribution system will not, therefore, generally be affected by the design of the internal systems of buildings connected to the DH network.

Most existing steam distribution systems were designed and built at the same time as the connected buildings. The systems were therefore optimized for the heating and DHW systems in the buildings. Where heating systems serve a number of buildings of different age, type and system requirements, the systems must be designed to serve the specific requirements for each buildings.

If consideration is being given to the installation of a district heating system in a developed area with commercial, industrial or high rise apartment buildings, the cost of the system will depend on the type of the existing heating systems in the buildings which are to be served. Costs for the substations to convert the buildings to the system may be lower where building systems are steam based and greater where the building systems are hot water based.

1.3 Building Connections and Substations

1.3.1 Substations

Heat Exchangers

There are many methods for connecting buildings to steam distribution networks. The steam can be reduced through a pressure reducing station and used directly as steam or it can be converted to hot water through the use of heat exchangers.

Direct Connection

If steam is to be used directly, the user's building system must be fully investigated to ensure that the pressure rating of all components in the system exceeds the distribution pressure. If all components do not meet or exceed the required pressure rating, several courses of action are available:

1) Replace the component or components in question with new components having the required pressure rating;

2) Reduce the steam pressure where it enters the

building prior to use;

3) Reduce the steam pressure of that portion of the steam serving the system components which do not meet the required pressure rating. In all cases, pressure control is required;

4) Install a heat exchanger to generate secondary cycle steam at the required pressure for the building.

It is desirable, whenever possible, to keep the secondary system physically separate from the primary steam distribution network. With any of these options, the issue of condensate return must be fully investigated to ensure that adequate provision is made for the collection and return of the two different pressure condensates. Typically, the pressure of the high pressure condensate is reduced so that it equals the pressure of the low pressure condensate. In cases of direct steam usage for process purposes, condensate is not available for return to the system.

Most buildings or facilities which are connected to district heating systems are heated by hot water with hot water boilers as the heat source. In this situation, converters or heat exchangers are required to convert the heat energy in the steam to hot water which can be utilized by the existing heating system.

Where steam boilers are connected to the hot water heating system within the building, heat exhangers or converters will already be in place. Although it is not common practice, these exchangers could be connected directly to the DH network. In such cases it is extremely important to ensure that the pressure rating of the heat exchanger is capable of meeting the pressure levels of the district heating network. If this is not the case, a pressure reducing station and adequate relief protection must be provided for in the substation.

Although space heating is the major heat load requirement for a building, consideration must be given to the domestic hot water requirements of a subscriber. Domestic hot water may be generated by a coil heated tank (either steam or hot water) or by the use of an instantaneous heat exchanger. It should be noted that because of the relatively high year-round temperatures of the steam distribution system, DHW can be heated through the use of secondary tank coils and instantaneous heat exchangers.

A typical substation schematic is indicated in Figure A 1.1.

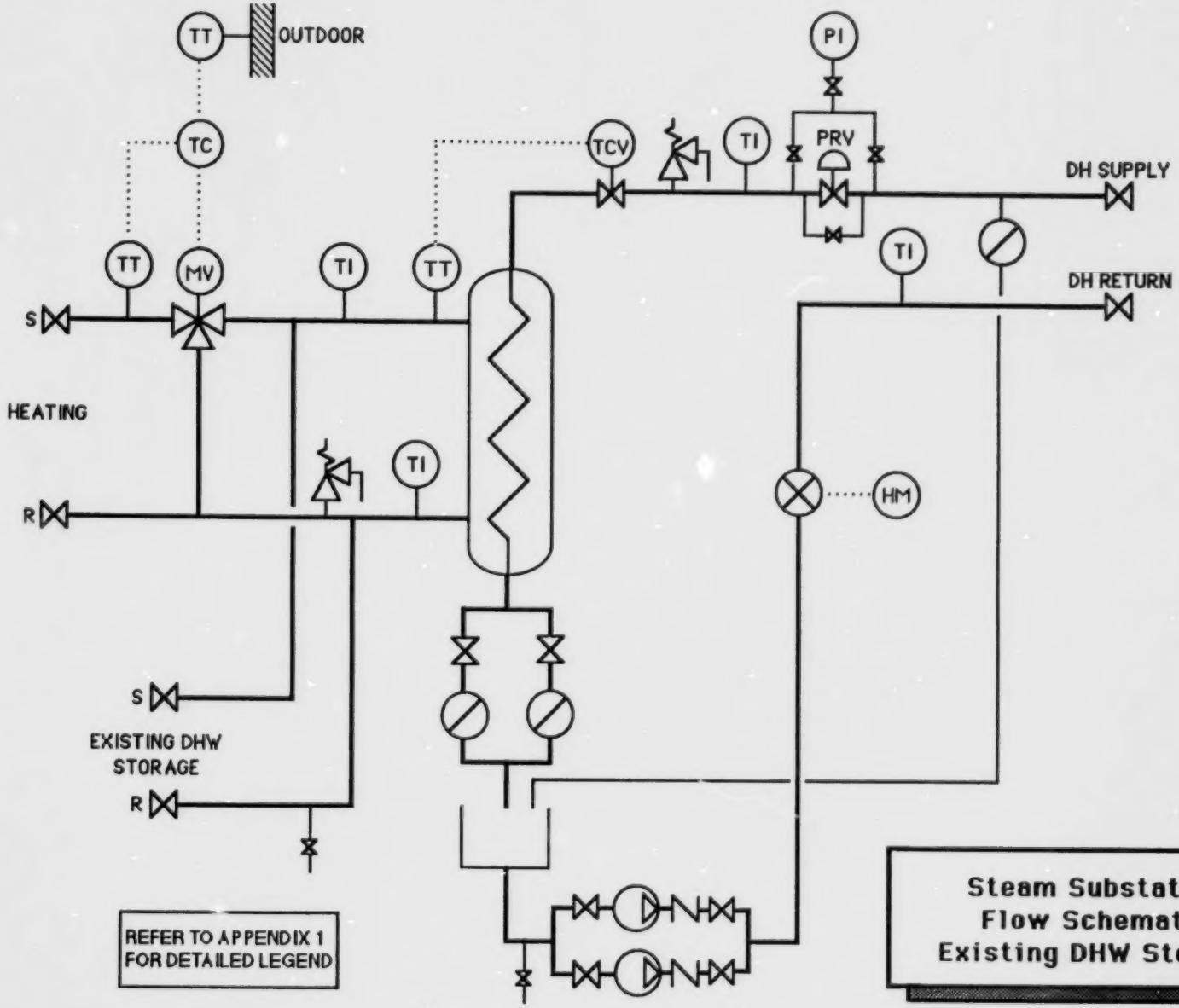


Figure A.1.1

Steam Substation
Flow Schematic
Existing DHW Storage

Condensate

In many large steam distribution systems, condensate is not reclaimed, but is sent to the local municipal or storm sewer system. This condensate must be cooled to at least 55°C before it is released into the sewage system.

If the customer is a large user of domestic hot water the high temperature condensate can be used to preheat the DHW by means of a heat exchanger. The arrangment is quite similar to the three stage couplings used in hot water district heating. The high temperature condensate could also be mixed directly with cold water before it is sent to the municipal sewage system.

Where the building is heated with hot water or low pressure steam, the 7-14 bar g (100-200 psig) steam must usually be reduced before it is used. When the steam is passed through a heat exchanger, it must be reduced to a lower pressure because the steam would otherwise condense at high temperature and then flash off in an open condensate tank. An alternative is to cool the high temperature condensate in a condensate heat exchanger. The condensate is collected in a condensate tank and pumped back to the boiler plant.

1.3.2 Metering

Measurement of the amount of thermal energy delivered to buildings connected to DH systems is desirable for several reasons. Where the buildings are owned by the same firm or organization, energy management within individual buildings can only be enhanced with knowledge of the levels of energy consumed by each building. If industrial process requirements are involved, cost accounting systems may require the determination of energy use for each connected facility. For DH systems which serve buildings with different owners, measurement of energy delivered provides the basis for billing the owners.

Measurement of thermal energy delivered in steam systems can be accomplished in a variety of ways depending on the specific application. If steam is used directly by the customer and no condensate is returned, the customer would normally pay for the steam on the basis of dollars per unit of steam used. Steam flows are metered and the customer is billed on the basis of the established unit cost of the steam. Steam flow meters are relatively expensive at $5,000-$50,000.

If condensate is returned to the district heating plant, the measurement of condensate return can provide the basis for

measuring thermal energy delivered. Although condensate flow meters are inexpensive, they measure only condensate flow and not changes in temperatures. Consequently, their accuracy is limited to approximately +/- 10%.

If meters are used for billing to the customer, more accurate metering is sometimes required. In this case, both the flow and temperature of the steam into the customer facility and the flow and temperature of the condensate returned from the customer must be metered. An integration unit may then be used to calculate the energy consumption. Such a metering system is very expensive.

The value placed on the cost of the energy must take into consideration the system heat loss as well as generation and maintenance costs. Furthermore, if steam is used for humidification, process or other purposes, the condensate does not reflect the true level of energy use. Both steam and condensate measurements should be incorporated in the billing procedures.

A condensate meter is a simple flowmeter that meters the returned condensate. These condensate meters cannot measure steam losses arising from flash-off steam from the condensate tank or system losses resulting from leakage or from mechanical problems.

The most common types of steam meters in use today are orifice plate and turbine meters. The accuracy of both of these meters is greatly reduced at low flow rates or where there is a variation in steam pressure. Variations in steam pressure can be measured by pressure compensated flow meters. The flow computer continuously monitors steam pressure through a transducer and makes corrections for the specific volume of the steam at various pressures.

Steam meters are expensive and in most cases it is not cost effective to use steam meters for small subscribers.

1.3.3 Controls

Substation controls for steam district heating systems have traditionally been self contained or pneumatic. Each individual substation should have a pressure regulating valve (PRV) on the main supply to the customer's building. This PRV can be set to supply a constant pressure to the customer.

Care must be taken to ensure good control over the individual processes within the customer's building i.e. domestic hot water and space heating. To control both of these processes, combined temperature and pressure regulating valves are

commonly used. These control valves can either be self contained or electrically activated. Electronic controls are being used in increasing numbers in both steam and hot water systems. These compact but relatively sophisticated controls give a higher degree of control flexibility than the conventional self activated control valves.

1.4 Steam Distribution System

1.4.1 Configuration

Installation

Steam district heating distribution systems can be and are installed in numerous ways. The most common of these are:

1) Direct buried insulated pipe;
2) Pipe installed in box type conduit;
3) Pipe installed in tunnel;
4) Pipe installed above ground on pipe racks;
5) Combination of any of the above.

Typical configurations are illustrated in Figures A1.2a and A1.2b. The determination of which approach is preferable is based on existing street services and other factors.

The pipe fittings normally used for the distribution of steam are made from carbon steel. The technology for the use of carbon steel pipe for this application is well known and proven to meet ASME/ANSI B31.1 temperature and pressure requirements for pressure vessels. Standardized manufacturing and testing of materials, as well as proven installation techniques all support the decision to use steel pipe for this application.

Carrier piping which transports the steam from the power plant to the building is usually made from Schedule 40-Schedule 80 carbon steel.

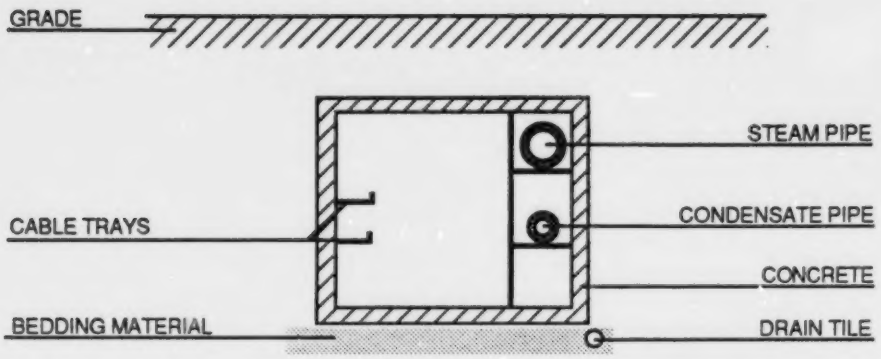
Steam piping systems include:

1) tunnels or box conduits, the carrier pipe insulated with fibreglass and covered with asphalt paper or equivalent;

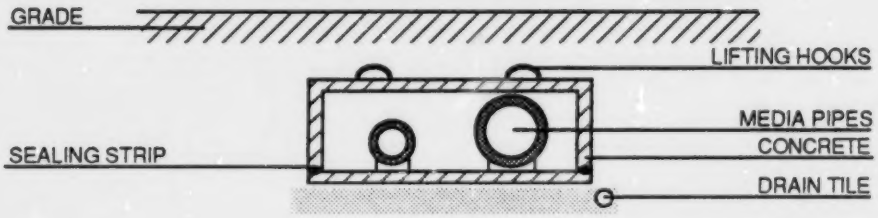
2) directly buried pipes with fibreglass insulation and sheet metal casing, poured in concrete with bituminous coating;

3) steel-in-steel pipes;

Figure A.1.2a

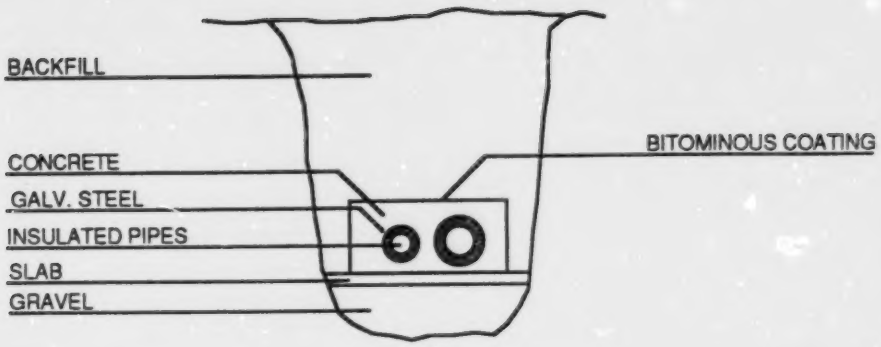


Tunnel

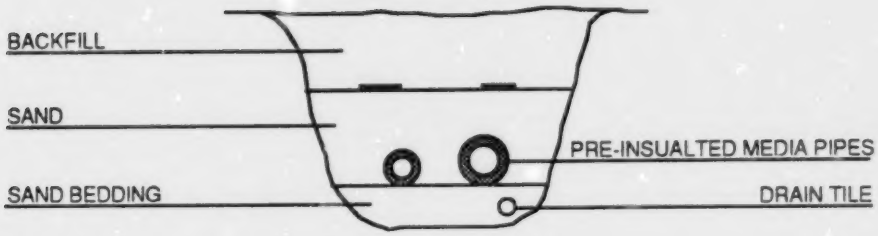


Box Conduit (SIT)

Steam Distribution Cross Section



Direct Buried Pipes
Poured in Concrete



Direct Buried Pipes
Pre-insulated

Steam Distribution
Cross Section

4) carrier pipe with two layer inorganic/polyurethane insulation with polyethylene jacket for direct burial.

Tunnels

Figure A1.2a shows a typical tunnel section. Tunnel systems can be foung mainly in institutional environments, such as university campuses. In these situations the tunnel system is used to carry other services such as power and telephone. Tunnels provide easy access to the steam piping for inspection and maintenance. However, they are very costly to install.

Buried Systems

Buried systems can be installed using various methods. The box conduit is one such method for installing steam lines. Figure A1.2a shows a section through the steam inverted tunnel (SIT) system. The carrier pipe, insulated with fibreglass and covered with canvas or aluminum, is supported along the conduit base by saddles. The inverted tunnel section is placed on the conduit base forming the box. Care must be taken to ensure that the box is impervious to water. This conduit system is used extensively at Canadian Forces Bases.

Enclosing pipes in a continuous concrete pour is another method of direct burial. The pipes are insulated in the normal fashion and encased with galvanized steel. With the pipes laid in the trench, concrete is then poured, completely covering the pipe system. This system is illustrated in Figure A1.2b.

The steel-in-steel prefabricated system comes complete with carrier pipe, thermal insulation and outer casings. The carrier pipe is supported radially by the outer casing and is surrounded by fibreglass insulation. The pipe sections come ready to be assembled on the site. The outer casing is coated with epoxy to protect the outer casing from corrosion. Special care must be taken during installation and backfilling so as not to damage the epoxy coating. This is crucial if the integrity of the system is to be maintained.

Manholes or concrete chambers must be built where required for low points (traps, condensate receivers, pumping sets), sectioning valves and other points. Electrical power supply must be available in the manholes for most controls. The manhole must be built to accomodate a maintenance man as well as all equipment in order to provide for maintenance requirements. The equipment located in steam system manholes requires regular maintenance in order to work properly. The

manholes must also be properly drained and require pumps for drainage.

Condensate Removal

Condensate which is removed from the distribution piping throughout the system should be collected and returned to the point of steam generation. This condensate contains heat energy and the more condensate that can be collected and returned at a reasonable temperature, the greater the savings.

The issue of condensate removal must be addressed even if the condensate is not returned to the boiler plant. The build-up of condensate has two major adverse effects on the distribution system. First, the presence of condensate in distribution piping reduces the effective cross-sectional area of the carrier and the carrying capacity. Second, condensate buildup may create "water hammer". Condensate can be moved by the steam at very high speeds. When the water encounters an obstruction, the momentum of the water is dissipated rapidly. This impulse force can far exceed the forces exerted by system operating pressures and cause damage to the system.

Provision for condensate removal must be made at all low points in the system. Well maintained condensate removal points are very important for extended system life.

Depending on the system design, length and pressure, condensate receivers, flash tanks and condensate pumping sets may be required at various locations (normally in manholes or valve chambers) to return the condensate. This equipment adds to the maintenance and operating costs of the system.

In many of the larger steam systems such as the Toronto district heating system, the condensate is not returned to the distribution plant. Instead the utility elected to use an intense water treatment program for continuous feedwater make-up. This was seen as an alternative to installing and maintaining a condensate return system, which is a high maintenance item.

Condensate Return Systems

In cases where condensate is returned, it is collected in unpressurized tanks open to the atmosphere. As a result, the condensate contains oxygen and becomes extremely corrosive unless properly and continuously treated. Due to the corrosive nature of condensate, condensate return systems have caused major problems in many return systems and led to high maintenance costs as well as numerous cases of

condensate loss.

The treatment of steam with filming and neutralizing amines has reduced system corrosion problems. However, there is a significant recurring cost associated with the treatment and maintenance of these systems because of the high cost of the chemicals and the work involved.

Condensate piping is normally made from schedule 40-80 carbon steel. Reinforced fibreglass for condensate piping is also very common, but has pressure and temperature limitations.

Some condensate return systems have recently been installed using fibreglass-reinforced epoxy thermoset plastic pipe and fittings. This material is available in sizes up to NPS 16 and is suitable for pressures up to 10 bar g at 93°C. The use of this material appears to be acceptable and the cost is competitive. Care must be taken during the installation to ensure that the manufacturer's recommendations with respect to joints, bedding and compaction are followed.

1.4.2 Heat Loss

The heat loss from a distribution system is a function of the temperature differential between the distribution medium and the surroundings, the type and quantity of insulation and the method used for pipe installation. Heat losses will also occur from the carrier pipe through spacers, supports and flanges that cannot be fully insulated. Exposed joints and valves also add to the heat loss. These characteristics, combined with the high operating temperatures of steam systems, result in high heat losses for steam distribution systems.

When the space heating requirements decrease in the summer, the supply steam pressure and consequently the temperature can sometimes be decreased (particularly if the use of absorption chillers is limited or absent). This will help to reduce both the "normal" heat losses and heat losses that occur through leaking traps, valves and other components of the system. In some cases, it may be possible to shut dowm the steam system and achieve significant savings.

1.4.3 Allowance for Expansion

During the design of the system, the subject of pipe expansion/contraction must be carefully considered. The rate of expansion in a steam distribution system is normally high because high temperature variations are experienced. In systems using carbon steel piping and operating at approximately 200°C, the amount of expansion based on an

installed temperature of 21°C would be approximately 225 mm/ 100 m. This expansion can be handled in a number of ways, such as:

1) Linear expansion compensators;
2) Swing joints;
3) Expansion loops;
4) Natural pipe flexibility.

The method selected is normally a function of factors such as the system route and the method of installation. Linear expansion compensators, for example, are a relatively high maintenance item and would likely be used where the system would be accessible for maintenance i.e. tunnels and chambers. Expansion loops are commonly used in directly buried systems.

1.4.4 Leak Detection Systems

Directly buried and box conduit systems should contain a method of leak detection which can pinpoint the location of system leaks. One method employed is the utilization of an empty conduit along the distribution piping through which a microphone can be drawn to establish the area of the leak. Drain lines can also be used so that water from leaks collects at a low point and can be removed.

Direct leak detection systems are not normally used in steam systems because of low reliability and difficult detection. System efficiency therefore suffers because thermal energy is lost and costs of treating make-up water are increased when leaks are not readily detected.

1.4.5 Supply Reliability

The reliability of a steam distribution system can be increased in the following ways.

1) Two parallel supply and return lines;
2) Loop the system;
3) Supply plants at each end of the system.

Because a high degree of reliability is not a major consideration in most cases, steam systems generally consist of a main trunk line feeding from the plant with smaller feeder lines serving blocks of customers. It is possible in situations like this that the main line can be fed with steam from a plant located at another point in the system.

1.5 Production Plants

Steam systems create the necessary energy for transport through increased steam pressures. Increases in pressure require higher saturation temperatures based on higher steam temperatures. The result is higher flue gas temperatures. Unless economizers are utilized, efficiency will decrease and more fuel will be needed to achieve the higher steam pressure.

The treatment and deaeration of feed water are critical to ensure a long life and high efficiency of the boiler system. Such water treatment is relatively expensive and requires extensive monitoring, particularly where low rates of condensate return require significant quantities of make-up water on a continuous basis.

If the steam is passed through a backpressure turbine, the power yield will suffer at high levels of backpressure. If district heating system temperatures are 100°C (1 bar g), the power yield will be much higher than if the steam is expanded to only 8-14 bar g.

Low temperature heat sources, such as industrial heat, cannot be utilized with steam distribution systems. Thermal storage tanks which assist with the management of peak demand and overall system efficiency cannot be utilized with steam distribution.

1.6 Maintenance and Operation

Operation and maintenance of steam systems requires much attention. For example, the feedwater must be carefully treated and the condensate and make-up water must be monitored.

The steam distribution system consists of many mechanical parts that require maintenance. Such parts include traps, valves, condensate pumps and steam and condensate meters. Preventative maintenance is extremely important in steam systems.

The steam distribution system includes many joints which require routine inspection and maintenance. For example, steam traps, pressure regulating valves, condensate pumps, shut off valves and expansion joints must all be maintained. Leaks must be kept to a minimum and traps must be maintained to ensure adequate condensate removal from the distribution system.

An intensive program of water treatment must be followed to

ensure that the integrity of the piping system for both steam and condensate is maintained. Manholes must be inspected regularly for their structural integrity and for any signs of excessive condensation.

The main objective in the operation of a system is to keep major rapairs to a minimum.

1.7 Availability of Technology

Steam technology is widely understood and utilized throughout Canada. Engineering expertise, materials and equipment are readily available.

2.0 Design Principles of Hot Water Distribution Systems

2.1 Hot Water Distribution Systems Alternatives

During the past 40 years, many European countries have turned to hot water distribution systems as the basis for new large municipal DH networks. Based on extensive research activities as well as extensive system experience, it has been concluded that where space heating is the predominant requirement, these hot water systems provide for lower capital and operating costs compared to steam distribution systems. Hot water systems can utilize low grade waste heat (readily upgraded by heat pumps) as well as sources of alternative energy, such as municipal waste and wood chips.

Hot water district heating systems are used primarily for three applications:

1) space heating;
2) domestic hot water;
3) Process applications.

With very few exceptions, the systems are closed loops where no water is lost from the system.

Cooling loads cannot usually be served with hot water distribution systems. Cooling loads are typically served through either district cooling systems or individual electric air conditioning units.

From an organizational point of view, three different system applications can be defined:

1) Institutional: Multiple-building institutions such as universities and hospitals, typically having a single owner;

2) Municipal District Heating: Many different subscribers connected to the same system;

3) Industrial: Multiple-building industrial sites with process and/or heating applications.

The principle variants in hot water distribution systems are the temperature level of the water and the means by which thermal energy supplied by the DH system is utilized in the connected building. Typically, the water temperature is governed by the requirements of the buildings to be connected. Overall, temperatures are kept as low as possible to minimize heat losses in the network.

Connections to hot water systems may be:

1) Direct: water from the distribution system is circulated through the subscriber's heating system;

2) Indirect: a heat exchanger is used to isolate the subscriber's system from the distribution network.

With indirect connections, the temperatures and pressures needed to optimize the efficiency of the DH network do not have to be compromised by limitations and differences among the subscribers internal heating systems.

Although the technology of hot water distribution systems for district heating is well established in many countries, there are a number of significant differences among the systems in operation. Differences in user requirements and local codes have led to the development of different distribution system philosophies, even though the basic ideas and concepts are the same.

For example, the high pressure rating of internal piping in buildings in West Germany has allowed the increased use of direct connection in some DH systems. In Denmark, where many single family homes are connected to DH systems, the higher relative cost of small substations has led to the use of directly connected residential sub-systems indirectly connected to larger systems. In Sweden and Finland, indirect connection with heat exchangers is the predominant method for connection. Special supply situations also add requirements to the distribution system. For example, where congeneration plants are utilized, a low return temperature level is particularly important.

Three major alternatives are used (with minor variations) to meet user as well as system requirements:

1) Low temperature/pressure:
80^{o}-95^{o}C peak supply temperature, closed loop, direct connection, 2-10 bar g pressure;

2) Intermediate temperature/pressure:
90^{o}-120^{o}C peak supply temperature, closed loop, direct or indirect connection, 5-25 bar g pressure;

3) High temperature/pressure:
130^{o}-200^{o}C peak supply temperature, closed loop, indirect connection, 20-40 bar g pressure.

Low temperature systems are normally used in smaller systems where the temperature requirements are limited and the system size necessitates simplicity and safety. Staffing

requirements are low. The system is often used in institutional and industrial applications without process heat. Because of the limited operating temperature and pressure, buildings are often directly connected.

Medium or intermediate temperature systems are the most common for district heating systems. A higher peak supply temperature reduces design water flow and pipe sizes. The system must be pressurized to avoid flashing of steam as a result of the higher temperatures. Pressure differentials up to 20 bar g allow extensive systems to be built with few pumping stations. Limitation of operating temperature to 120°C makes it possible to use low cost preinsulated, directly buried, thinwall pipe.

Because of relatively high operating pressure, subscribers or groups of subscribers are usually connected indirectly through heat exchangers. If direct connection is used, arrangements with mixing valves, pressure reducing valves and safety valves have to be used to provide safety and comfort. Leak protection systems and water treatment are used to increase the lifetime of the system and minimize maintenance costs.

High temperature systems are used mainly in industrial process applications and for large DH mains and are found in older district heating systems. For large transmission mains, (typically with Dia 600 mm) the most cost effective approach can be to build the piping system on site with concrete tunnels and fibreglass insulation. Flow rates and pipe sizes can then be reduced by a high supply temperature (130-200°C). Because of the high temperatures and long distances, the operating pressure is usually very high, often 20-40 bar g. This system type is also used for industrial process applications, where the high temperature is a process requirement. Before the introduction of preinsulated pipe with polyurethane foam in 1960-70, most district heating systems were built with concrete conduits and fibreglass pipe. Operating supply temperatures were often high in order to minimize pipe sizes and installation costs.

Many variations of the three basic types of hot water systems can be found for different applications. The parameters and requirements of each individual application may provide a framework for optimization that may result in a system configuration that varies from the ones described above.

2.2 User Requirements

The objective of a district heating system is to meet the end users heating requirement efficiently and reliably.

In the northern part of Europe, where radiators are used extensively instead of perimeter heating, the design temperatures of space heating are usually 80°C supply and 60°C return resulting in a 20°C temperature drop. Canadian systems with perimeter heating and separately controlled zones often have only a 5-10°C design temperature drop. Such systems are usually designed for 85-95°C supply temperatures. The high supply temperature and low temperature drop results in high flow rates and high return temperatures which are undesirable in hot water distribution. In addition, ventilation systems often operate with relatively high temperatures and limited heat-transfer areas. The low temperature drop through the subscriber's heating system limits the amount of energy the distribution system can deliver. If the temperature drop could be doubled, for example, the distribution system could supply twice as much heat through a given heat exchanger. Accordingly, subscribers should be encouraged to examine ways to realize a greater temperature drop within their buildings.

The concept of bypassing heating water not used in a heating unit also contributes to high flow rates and return temperatures. Through simple modifications, such bypasses can be cut off to better suit a DH system.

Existing building systems are often operated at unnecessarily high supply temperatures year round. In most cases, the actual user requirement can only be established through on site testing. In one Canadian DH pilot project, most users had been operating their individual boilers at 80-95°C year round, with a return temperature drop of 5-10°C. After connection to the DH system, it was found that the real user requirements were:

Space Heating:	winter	70-90°C
	summer	35-50°C
Domestic Hot Water:		55-65°C

Depending on how the connections were made, the return temperatures were:

Overall System:	winter	50-80°C
	summer	25-45°C

Buildings with continuously running distribution pumps work well with DH. However, buildings with individually controlled pumps in different sections of the building create a potential control problem. Buildings with only one thermostat-controlled pump can result in fluctuating high temperatures. However, the impact on the system will be low if these buildings make up a small percentage of the total demand.

Buildings with steam systems can normally not be served with a hot water DH system and must therefore be converted. Since few modern buildings are heated with steam, the total increase in DH project cost for such conversions is therefore small. Experience in the United States indicated that substantial energy savings could be achieved when converting steam heated buildings to hot water. The savings may offset most of the cost of conversion.

Process applications which utilize high temperature hot water or steam are not usually suitable for modification or conversion to district heating because the costs are prohibitive. Minor loads might not be included in the DH system, while major loads might be connected through separate high temperature hot water or steam lines.

Cooling loads cannot usually be served through a hot water DH system. Existing absorption chillers must therefore be supplied from the existing steam source. Alternatives include a parallel district cooling system with central chillers or the replacement of the absorption chillers with electric chillers.

2.3 Building Connections and Substations

2.3.1 Substations

When a building is connected to a DH system, a substation consisting of a heat meter, valves, heat exchangers and control system is normally installed at the connection point. Different types of substations have been developed to meet the different system applications and needs of users. Major variations include:

1) Direct connection
   a) no mixing
   b) mixing connection
2) Indirect connection
   a) parallel coupling
   b) 2-stage coupling
   c) 3-stage coupling

Direct Connection

The simplest method of connection is the direct connection method. The water from the district heating system passes through the heating system of the building. In the mixing connection, the DH water is mixed to a lower suitable temperature in the substation. In the connection without mixing, the DH water is passed directly through the building circuit.

Heat Exchangers

Heat exchangers are used for indirect connections which physically separate the DH system from the internal system of the building. This design approach provides the capability to operate the building and DH distribution systems at different temperatures and pressures. The DH system can therefore be optimized at high temperatures and pressures without concern for the internal system of the building.

Indirect connections are usually built as parallel, 2-stage or 3-stage couplings. In the parallel coupling, one heat exchanger is used for space heating and another for domestic hot water. In the 2-stage and 3-stage couplings, the primary return from the space heating heat exchanger is used to preheat the domestic hot water. Using these connections, a lower DH return temperature can be achieved. The 3 stage connection features a very fast DHW control because there is a mixing valve on the secondary side. The 3-stage coupling should not be used with hard water, because of the high risk of calcium deposits at high temperatures.

The 2 and 3-stage couplings are more expensive to build but result in lower return temperatures, lower heat losses, smaller pipes, and higher power yields if cogeneration equipment is used at the central plant. While the parallel and 2-stage couplings are common in hot water district heating, the 3-stage coupling is uncommon.

Flow Schematics of the different types of substations are shown in Figure A2.1a and A2.1b.

2.3.2 Metering

The customers of multiple-subscriber DH systems are charged for the energy consumed based on two different approaches to metering. One simple method, which is uncommon in current systems, is to charge the customer based on the DH water flow through the substation. This method is inequitable because a customer with a low temperature drop will be charged more per unit of energy than a customer with a high temperature drop. The method has been used to encourage customers to return the DH water as cold as possible, which is desirable when back pressure turbines are used for cogeneration.

The most common method to meter the consumed energy is to meter DH water flow, supply temperature and return temperature. The data are integrated to calculate and accumulate energy consumption.

The main limitations of heat meters are the relatively low

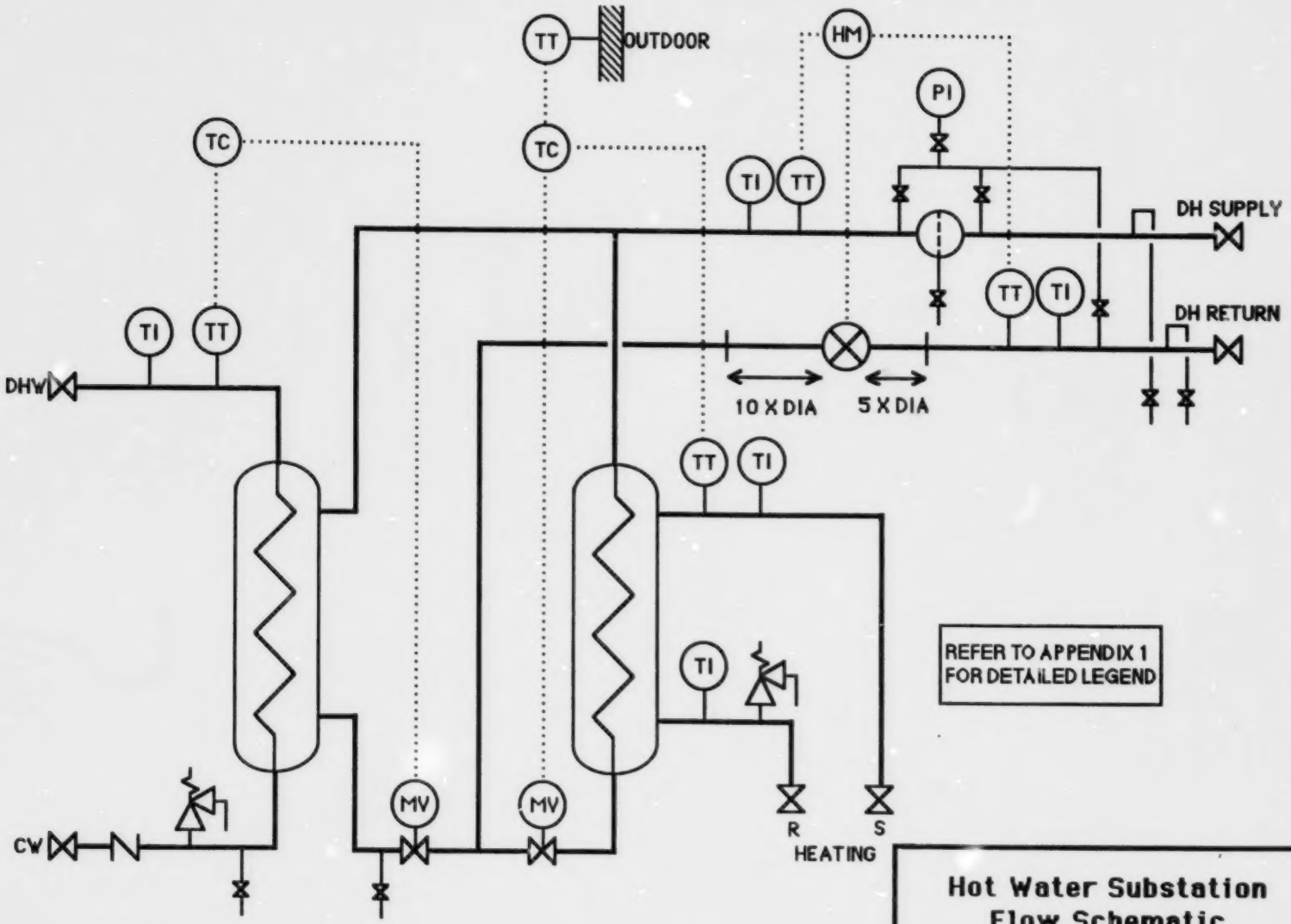

TT
OUTDOOR
HM
PI
TC
TC
TI
TT
DH SUPPLY
TT
TI
DH RETURN
TI
TT
DHW
10 X DIA
5 X DIA
TT
TI
TI
REFER TO APPENDIX 1
FOR DETAILED LEGEND
MV
MV
CW
R
S
HEATING
Hot Water Substation
Flow Schematic
Parallell Connection

Figure A.2.1a

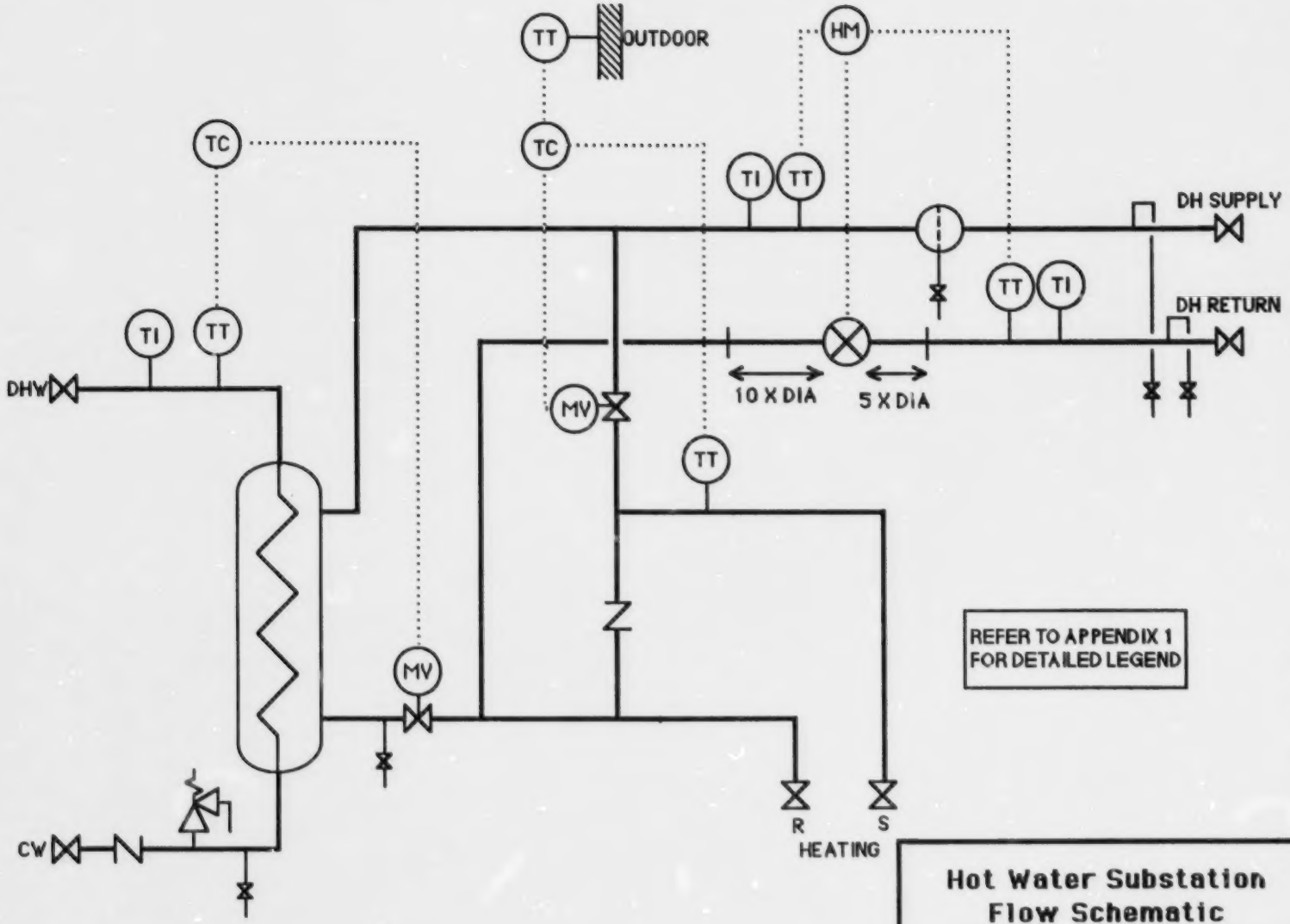


Figure A.2.1b

Hot Water Substation
Flow Schematic
Direct Connection

accuracy and high cost of small units relative to the total substation cost. The cost of heat meters does not decrease proportionally with decreased capacity and may be a significant part of the substation cost of a single-family unit. Meters for capacities less than 100 kW cost approximately $1,300.

The accuracy of the heat meters is related to the cost. In Sweden, only meters with accuracy better than +- 3% are approved for use in DH systems. Most meters for DH applications offer an accuracy of +- 2% in the normal flow rate range (5% to 130% of nominal flow rate). Heat meters are subject to registration and approval in many countries in order to ensure satisfactory accuracy.

Different types of flow rate meters used in DH systems include:

1) fluidistor meters;
2) turbine meters;
3) winged wheel meters;
4) induction meters.

While winged wheel meters have been commonly used for a long time in hot water DH systems, induction meters are becoming increasingly popular as prices drop and smaller sizes become available.

Even though meters are recognized as one of the main areas for research and development in DH, the current problems with meters are not sufficient to constrain the further expansion of DH systems.

Comparison of Substations

Special considerations have to be given to the choice of connection method. The direct connection is less expensive than indirect connection with heat exchangers and may offer significant savings for a DH project. However, the feasibility of direct connection may be constrained by the design of the internal system of the buildings.

Where the internal system pressure rating is 2 bar g (30 psig), it is not practical to use direct connection unless the DH system is very small and the pressure drop between the supply and return is very low. The return pipe is usually oversized to reduce the pressure drop in the DH system because the pressurization pressure and the pressure drop in the return pipe must not exceed the return pressure in the internal system of the building. Supply temperature would also have to be limited to less than 100°C because the system cannot be pressurized to prevent flashing of steam. Pipe

sizes would therefore have to be increased further because the difference between supply and return temperature is reduced.

Directly connected systems should only be considered when the customer's internal system has a sufficiently high pressure rating (for example, 5-10 bar g) or when the extent of the DH system is very limited. The required pressure depends on the size of the DH system.

The use of differential pressure controllers, relief valves and mixing valves should be considered in order to reduce the risk of excessive temperatures and pressures in the internal system.

Leaks must be kept to a minimum in hot water DH systems in order to increase the lifetime of the system. When direct connections are used, the DH hot water is passed through the internal system of the building which should therefore be in good condition and without leaks. Inadequate maintenance and the bad condition of the mechanical systems in many buildings would tend to substantially shorten the life of a DH system using direct connection.

A special problem with direct connection in large DH systems is pressure surging. For many major DH systems, pressure surge calculations have been carried out in order to calculate and minimize damage at uncontrolled pump stops, valve closings and other points. In Canada, most hot water DH systems are still small and this problem is of little concern.

The investment cost for indirect connection is higher than for direct connection. However, if differential pressure controllers and mixing valves are considered essential to provide equal comfort in a direct connection system, the difference in cost is small.

The use of heat exchangers offers more flexibility in the design of the DH system. Because the DH and building systems are physically separated, the DH temperature and pressure can be at higher levels. The ratings and conditions of the internal system are of less importance and leaks and corrosion in the internal system do not directly affect the DH system.

Pressure surges in the DH system do not directly affect the internal systems when heat exchangers are used. The DH system becomes a well defined closed loop that is easier to control and maintain. It is also easier to resolve any ownership and liability questions. Insurance costs can be expected to be lower.

The main disadvantages of systems with heat exchangers are the higher investment cost of substations and higher supply and return temperature that result. The return on the DH side is typically 5°C higher than the return temperature on the building side.

If backpressure turbines are utilized for cogeneration at the DH boiler plants, a low return temperature will permit a higher level of electrical output (because the steam through the turbine will be condensed at lower pressures and temperatures, the differential pressure over the turbine will increase). A low return temperature also facilitates the more efficient utilization of low temperature heat sources, such as heat pumps operating at temperatures up to 70°C.

The peak supply temperature during the winter is not as critical when heat-only boilers are used for peaking and are operated in line with the low temperature heat source. These boilers can increase the supply temperature without limiting the utilization of the low temperature heat source or decreasing the turbine power yield at cogeneration.

2.3.3 Controls

In hot water distribution systems, the hot water is distributed in a closed loop to the substations. The flow rate of the system is determined by how much water the substation controls and how much the bypass is letting through to the return line.

The substation controls the building's heating system or DHW temperature by regulating the supply of heat from water in the distribution system. The heating control system usually consists of a 2-way control valve in the return line on the primary side of the substation. The control valve is connected to a control that regulates the position of the valve based on a sensor in the secondary side supply line, an outdoor sensor and correlation factors that can be adjusted on the control panel. In this way, the internal system in the building is operating at a higher temperature level as outside temperatures drop.

The controls can be electronic, pneumatic or thermal self-controlled. Modern electronic systems feature options such as Proportional, Integral and Derivative (P,I and D) functions, "soft" night setbacks, "coldest room sensor" control, and remote control.

The DHW control is similar to the heating system control except that it has no outdoor reset function and instead maintains a constant DHW temperature which can be adjusted on

the control panel.

Some modern hot water district heating systems feature central control systems for centralized supervision and control of the distribution system and substations. System information is collected in a central unit through remote readings, and, when necessary, control functions, such as limiting the maximum output of a substation, are preformed.

2.4 Hot Water Distribution Systems

2.4.1 Configuration

Pipes and fittings for transport of hot water are available in a broad variety of different materials, including:

1) Carbon steel
2) Ductile iron
3) Concrete
4) Glass fibre reinforced polyester
5) Polyethylene
6) Polyvinyl-chloride and other plastics
7) Copper

The absence of sufficient, reliable experience and experimental data for the application of concrete and other non-metal materials at high temperatures and pressures over long periods of time has limited the use of these materials in hot water DH applications except in smaller institutional and "block" systems.

The use of carbon steel pipes for hot water transport is the most common type for long distance medium and large diameter piping in systems operating at medium and high pressures. The standardized manufacturing and testing of materials and the proven techniques for joint welding and inspection have all contributed to the predominance of steel pipe for this application.

For small dimensions, copper pipes might be considered. These pipes are more expensive than steel but are easy and inexpensive to install.

Installation

Conventional insulation materials are available for above ground hot water pipes. Fibreglass is used for high temperature applications. Asphalt paper is applied to the insulation to protect the carrier pipe from corrosion. A jacket of galvanized steel or aluminum is often applied for external protection. For underground applications, the

conditions are more severe and special measures must be taken to protect the system from water and corrosion.

Three main systems are readily available and commonly used in DH systems:

1) Steel carrier pipe, polyurethane foam insulation and polyethylene jacket;

2) Steel-in-steel systems with carrier pipe and jacket pipe of steel. The insulation material is placed between the pipes;

3) Concrete ducts with steel pipes insulated with fibreglass and applied with asphalt paper.

Typical installation methods are illustrated in Figure A2.2.

Preinsulated Pipes

Rigid polyurethane foam is widely used as insulation material for preinsulated piping because of its low thermal conductivity, the suitability for mass production and the relatively low cost. Different makes and types are available. They all consist of a steel carrier pipe, polyurethane foam insulation (some manufacturers offer fibreglass for special applications) and a jacket made of polyvinyl chloride (PVC) or polyethylene (PEL, PEH). The objective of these configuations is to provide a watertight system in order to eliminate external corrosion. Preinsulated pipes with polyurethane insulation are available as a bonded system, where the steel pipe is bonded through the foam to the jacket and the whole system expands and contracts.

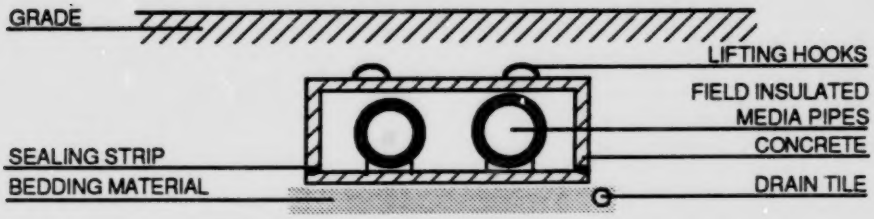
A variation of preinsulated pipes is the use of flexible copper pipes with fibreglass or foam insulation and a plastic casing. These are delivered in rolls and are particularly inexpensive to install since the pipes are simply brazed together.

Most suppliers offer a complete system including prefabricated fittings. A 5-year guarantee is common for these systems.

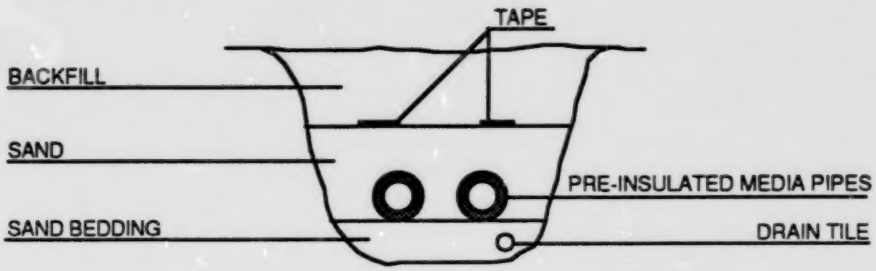
Steel-in-Steel Pipes

The steel-in-steel approach consists of a steel carrier pipe and a steel jacket pipe with insulation of glass fibre or granular inorganic material. This system is more expensive than pre-insulated pipe and is usually used in high temperature applications above 120°C, where polyurethane foam cannot be used. Steel-in-steel systems are available as

Figure A.2.2



Box Conduit



Direct Buried Pipes
Pre-insulated

Hot Water Distribution
Cross Section

bonded systems, and are therefore suitable for high temperature applications where thermal expansion would otherwise cause problems because of low flexibility and potential damage to the watertight casing.

Concrete Ducts

Concrete ducts usually consist of a duct within which the carrier pipes, insulation and asphalt paper protection are enclosed. Concrete ducts can be cast on site or be pre-manufactured. The system requires internal and external drainage systems as well as manholes at intervals. Concrete ducts are expensive and usually only feasible in large pipe sizes (Dia 600 mm). Properly installed, they have proved to be durable installations.

Manholes and Remote Valves

In order to shut off sections of the distribution system, shut off valves must be installed at desired locations. These can be installed either in manholes or as preinsulated ball valves with welded-body and welded-connections in the line to be operated from above ground. The latter type is predominant in Europe in small and medium diameters because of the relatively low capital cost. In Canada, the absence of competitively priced ASME/ANSI ball valves makes this approach more expensive than in Europe.

Manholes must be installed in high and low points in the system along with air-release valves and drain valves.

Thermal Storage

Thermal storage consisting of hot water tanks is often used in hot water DH systems. The storage is designed for short term (hours at full capacity) storage used for the following purposes:

1) Short term load levelling;
2) Utilization of low cost energy;
3) Short term capacity.

Termal storage systems are being used with storage capacities of several hundreds of thousands of litres. Two different principles are used:

1) Pressure vessel as a part of the system;
2) Atmospheric tank separated from the system through pumps and valves or a combined turbine/pump.

Under certain conditions, the function of the expansion tank and thermal storage can be combined. It is important to note

that the thermal storage capacity of the hot water distribution system itself can also be employed for limiting the heat load peaks. For example, the temperature level in the network can be raised during the night to meet the morning peak demand. In the case of combined heat and power generation, the heat demand can also be adapted to follow the electric power demand by employing special accumulators.

2.4.2 Heat Losses

Hot water DH systems are generally built with the following characteristics:

1) Closed loop;
2) Water treatment;
3) Water tight casing;
4) Leak detection system.

Much effort is spent to build and maintain a self-contained, sealed system. As a result, the total system heat losses are relatively small.

Heat losses in multiple-subscriber DH systems are usually in the range of 5-10%. The absolute heat losses are higher during the winter due to the higher temperature difference. However, relative losses are much higher during the summer when significantly less energy is distributed. Actual heat losses in a small Canadian system during its first year of operation were 4%. Typical heat loss for preinsulated pipe is approximately:

Dia	Heat loss (100°C carrier pipe, "plus" insulation)
25 mm	13.8 Watts/m
50	18.9
80	20.0
100	23.8
150	25.3
200	32.6
250	32.2
300	36.8
400	49.0
500	47.9

2.4.3 Allowance for Expansion

Two main techniques are used in designing hot water distribution systems to allow for expansion and contraction: free expansion adn restrained expansion.

Free Expansion

The principle of free expansion can be utilized in pipe installations above ground or in systems comparable to above ground installations, such as concrete ducts, unrestrained steel-in-steel pipes or preinsulated pipes with fibreglass insulation. Expansion is made possible by expansion devices such as loops and compensators.

Restrained Expansion

Two variations of restrained expansion techniques are used in the design of underground pipelines:

1) Friction-restrained systems
2) Friction-anchored systems

With a friction-restrained system, the surrounding soil restrains the pipe expansion and the expansion that does occur is taken up by expansion offsets or compensators.

In the friction-anchored system, the pipe is fully restrained by the soil and cannot expand excepts at bends. The friction-anchored system is less expensive to install than the other systems because the pipe length and the number of joints and bends are reduced. However, the system must be preheated during construction and then kept within defined temperatures to avoid excessive stresses.

Both systems are common in Europe. Preheating is becoming increasingly popular and is used where savings can be made and the longer installation period will not be too inconvenient. The choice of alternatives is related to factors such as:

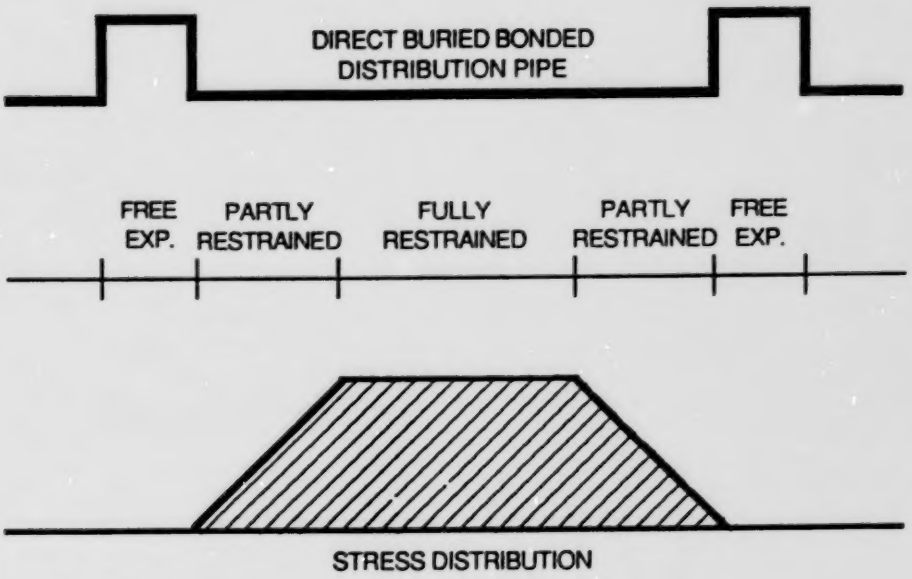
1) Area available for pipe routing;
2) Time available for construction;
3) Routing of the lines;
4) Possibility of keeping trenches open for extended periods;
5) Potential savings in expansion devices.

Figure A2.3 illustrates the restrained expansion principle.

Expansion Vessel

A hot water distribution system must be equipped with an expansion vessel to take up the change in water volume when the temperature changes. In a large DH system, the expansion vessel can be as large as 2-5% of system volume. The expansion system should be able to absorb volume changes due to seasonal variations in supply and return temperature.

Figure A.2.3



Hot Water Distribution
Restrained Expansion
Principle

Because the DH system is a closed loop, effort should be made to limit the expansion system's contact with the atmosphere and untreated feed water. This can be achieved with a steam or nitrogen "cushion" in the vessel that also pressurizes the system. When the DH system is pressurized through pumping, low pressure steam can be used to prevent oxygen in the vessel.

2.4.4 Leak Detection

No matter how well joints are made and checked, water leakage can occur occasionally from inside or outside the carrier pipe. Leaks can be the result of ground settling, external damage from digging, frost heaving or other factors. Most leaks occur because of a problem with the outer casing. If the leak is promptly identified and repaired, no corrosion of the carrier pipe will occur.

In order to discover any moisture in the insulation as promptly as possible, preinsulated pipes for direct burial are often equipped with an electronic alarm system. Any water will cause a short circuit which triggers an alarm. These systems are increasingly sophisticated and large networks can now be monitored from a central panel. Leaks can be located within a few metres and repairs can be planned and made efficiently.

In district heating systems in Sweden, an average of 1 leak/10 km per year has occurred from 1940 to the present time. The average cost to repair a leak was $6,000 in 1986.

2.4.5 Supply Reliability

The supply reliability of hot water DH systems can be increased in many ways:

1) Installation of 3 or 4 pipes instead of 2;

2) Connection of the mains in a circle so that water can be supplied from 2 directions;

3) Installation of peak and emergency boilers in opposite parts of the system;

4) Division of the DH system in sections by installing shut-off valves. A disconnected section of approximately 10 MW (peak) can normally be supplied during emergency situations from a 5 MW mobile boiler;

5) In certain installations emergency boilers are usually considered when especially high supply reliability is required (e.g. hospitals).

In Sweden, it is usually required that the system be capable of supplying half of the peak demand to all areas in the event of a break-down of a main feeder line. However, it is regarded as acceptable to supply areas with peak demand of less than 15 MW through the temporary connection of a mobile boiler plant in case of emergency. These are typically available in sizes up to 6 MW.

2.4.6 Temperature

The selection of the DH system temperature program involves a complex optimization of the various costs involved in producing, distributing and utilizing the energy. For example, a low temperature system will improve electrical generating efficiency from a back pressure turbine and reduce heat loss in the system. However, if, as a result, the temperature drop through the district heating system is reduced, then the flow rate increases and piping costs, pumping costs and heat losses increase.

The following temperature conditions are desirable:

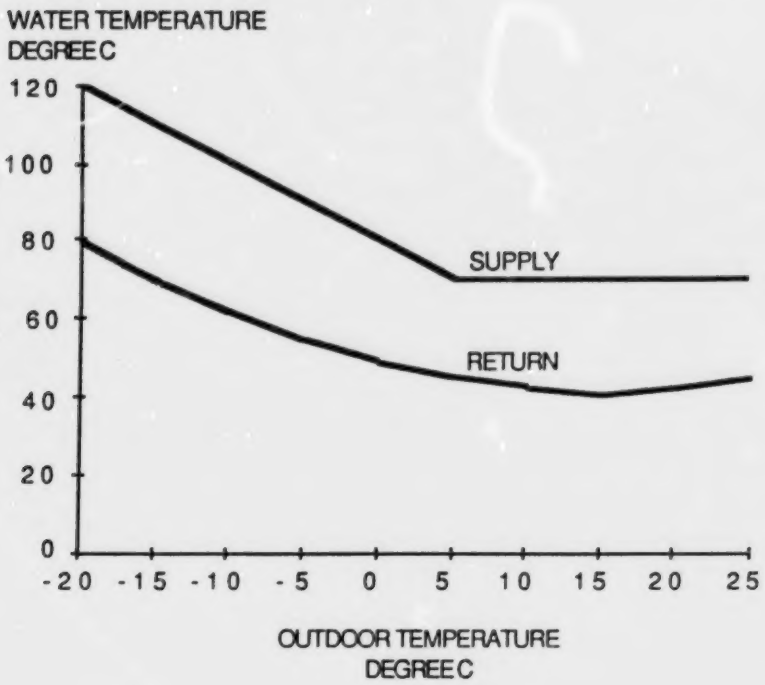
1) High supply temperature in order to minimize pipe sizes and piping costs;

2) Low return temperature in order to increase utilization and efficiency of low temperature heat sources and decrease heat losses;

3) Low average supply temperature in order to limit heat losses and increase the efficiency of heat-pumps, and back pressure turbines if cogeneration is incorporated.

While a low operating supply and return temperature is desirable, it might still be optimal to choose a high design supply temperature and then operate the system at as low a temperature as practical year round. A high design supply temperature reduces design flow and piping costs. The adverse impact on base energy production or waste heat utilization can be reduced if heat only in-line boilers are used to increase the supply temperature at peak load. A typical temperature program is outline in Figure A2.4.

Figure A.2.4



Hot Water Distribution Temperature Program

Low Temperature Systems

Low temperature distribution systems with a maximum supply temperature of 85-100°C have become more common in recent years. For existing systems, the supply temperature has been dropped as much as the system design and secondary system temperature requirements will permit. Many new systems are designed with a maximum supply temperature of 85-100°C.

In Scandinavia, where many low temperature systems have been installed, the design temperature is normally 90-100°C supply with a 50°C return. The low return temperature is critical to ensure that pipe sizes and installation costs are not significantly higher than for medium temperature systems.

In Canada, most existing buildings operate at a maximum supply temperature of approximately 85°C supply and a return of 75-80°C during the winter. While many buildings operate at lower temperature levels, there are also examples of much higher operating temperatures.

The connection of buildings with design operating temperatures of 85°C supply and 75°C return to low temperature systems would have the following implications:

1) Direct connection is preferred because the supply temperature of the distribution system is approximately the same as that within each building.

2) Direct connection limits the system's operating pressure and maximum pressure drop and increases pipe size;

3) The expected return temperature from the system will be approximately 75-80°C during design conditions;

4) A temperature drop of approximately 10°C will increase system flow rate 4 times compared to the normal temperature drop of approximately 40°C;

5) Distribution piping therefore needs to be doubled in diameter to accomodate the increased flow rate, which increases the capital cost;

6) Where substations are required to allow higher operating pressures in the distribution system, connection costs would also increase. For example, using an assumed temperature program of 90°/80°C on the primary side and 85°/75°C on the secondary side would double the cost of the heat exchanger and

increase the price of the substation by approximately 40-80%;

7) The reduction in heat losses during the winter months which would result from the lower design supply temperature would be offset by the larger pipe size required. During the remainder of the year, both systems are operated at comparable temperatures. The difference in heat losses between a low and medium temperature system is therefore insignificant;

8) Piping options, such as the use of fibreglass pipe, are increased when low temperature hot water is used. Fibreglass is significantly less expensive than Schedule 40 pipe. However, the price differential is not significant if thinwall carbon steel pipe can be used. Compared with thinwall pipe, the lower installation costs which result because welding is not required are offset by the concrete anchors or thrustblocks which are generally required;

9) If cogeneration turbines are used to supply energy, the power output will be increased during the winter months when the operating temperatures and, therefore, condensing temperatures are lower than in medium temperature systems. The actual impact depends on the design and performance of the power plant, the distribution system and the end-user system;

10) The use of low-temperature distribution systems also offers increased utilization of low-temperature heat sources during the winter months. However, many low-temperature heat sources, such as heat pumps, are run as base-load plants at 30-50% of the system's peak demand. Peaking boilers fired with alternative fuels such as oil are therefore required during the winter months which limits the potential savings from the low-temperature heat source.

Based on these implications it would appear that the use of low-temperature systems in Canada is limited to:

1) New distribution systems connecting a limited number of existing buildings, all operating at low temperature;

2) New distribution systems connecting new buildings designed for low temperatures and high temperature

drops.

Utilization of low-temperature systems with direct connection would limit the operating pressure of the system and therefore the practical system size. Where direct connection is not practical, utilization of low-temperature systems would significantly increase capital costs.

2.4.7 Pressure

The energy delivered in a hot water DH system is proportional to the mass flow rate. The flow of water is dependent on the pressure gradient which is obtained by pumping to provide sufficient pressure to overcome the friction resistance of the pipes. As the pipe diameter is reduced, the pressure necessary to provide the flow will increase.

For the same flow, investment cost will decrease with smaller diameter piping. However, the pump and pumping cost will increase as higher pressures are required. System pressure selection involves finding the minimum total cost of the system (capital cost plus pumping costs). The minimum cost system may represent an unacceptably high pressure at the pumping station for large systems served from one point. However, the problem can be solved by using more than one pumping station. This allows high pressure gradients and smaller pipes to be used without pressure drops building up to unacceptable levels.

Pressure Limitations

The maximum pressure limit is determined by the strength of the components in the system. When direct connection is used, special consideration must be given to the existing system within the buildings.

The minimum pressure limit is determined by the saturation pressure of the water. Because of differences in elevation in the system, the pumping station is not necessarily the place where the lowest pressure can be found. This minimum theoretical pressure must be adjusted for pressure drop in the boiler plant. These pressure limitations must be checked against a number of operational cases:

1) System running under design conditions;

2) Zero flow condition with the pumps running at design pressures;

3) Zero flow condition with the pumps off;

4) Transient flow conditions and pressure surges.

The limiting pressures should not be exceeded at any point in the system under any of the above conditions. Any safety valve or pressure reducing station which is not "fail safe" should be assumed not to have operated.

In practice, pressure ratings of approximately 6 bar g are found to be sufficient for most institutional systems, while most multiple-subscriber DH systems are rated at from 10 to 25 bar g.

Very high pressures are usually used only for long distance transmission lines operating at medium or high temperature or process requirements in industrial systems. In such cases, the system must be pressurized in order to prevent flashing of steam. The pressurization of the system depends on a number of factors, including:

1) Pressurization on the pressure or suction side of the pump(s);

2) Topography of system;

3) Relative elevation of pumping station(s);

4) Pressures under different operational conditions.

Many small and medium sized systems are pressurized at the suction side of the distribution pumps in the return pipe. Pressurizing pressure is usually in the range of 2-4 bar g.

Pressure Gradients

The determination of minimum total costs of the pipes and the pumping costs requires knowledge of pipe sizes and pressure gradients. In most cases, it is sufficient to use experience values on pressure gradients to calculate pipe sizes and pressures. If the maximum pressure is too high, more than one pump station can be used.

The optimal pressure gradient for many systems is 1-2 mbar/m. Higher gradients are possible. However, the high resulting velocity might create noise and erosion of the carrier pipe, especially at bends. Because of the limited number of different pipe sizes and the fact that the system does not often operate at design flow conditions, the average system pressure gradient will usually be lower than design values.

Variable Speed Pumps

Variable speed pumps with electronic converters or

transmission gears are common in district heating systems. The use of variable speed pumps controlled by means of an electronic frequency converter will enable part load operation to continue safely without wasting pumping power or increasing system pressures. The problem of controlling pressures at part load conditions is made much simpler because the pressure can be varied. The pumping costs are also reduced because less energy is wasted when compared to the use of constant speed pumps. The variable speed pump is a feasible investment for most DH systems, even though the price is considerably higher than that for constant speed pumps.

2.5 Production Plants

Production plants for hot water DH systems are usually designed as base load capacity and peaking and emergency capacity. A typical load duration curve for a multiple-subscriber DH system is illustrated in Figure A2.5. Where possible, base load plants should be fired with inexpensive low grade fuel, such as solid fuels and municipal waste. Other base load energy sources are industrial waste heat and heat pumps. Peaking and emergency capacity are usually provided by heat-only gas and oil boilers with low capital cost.

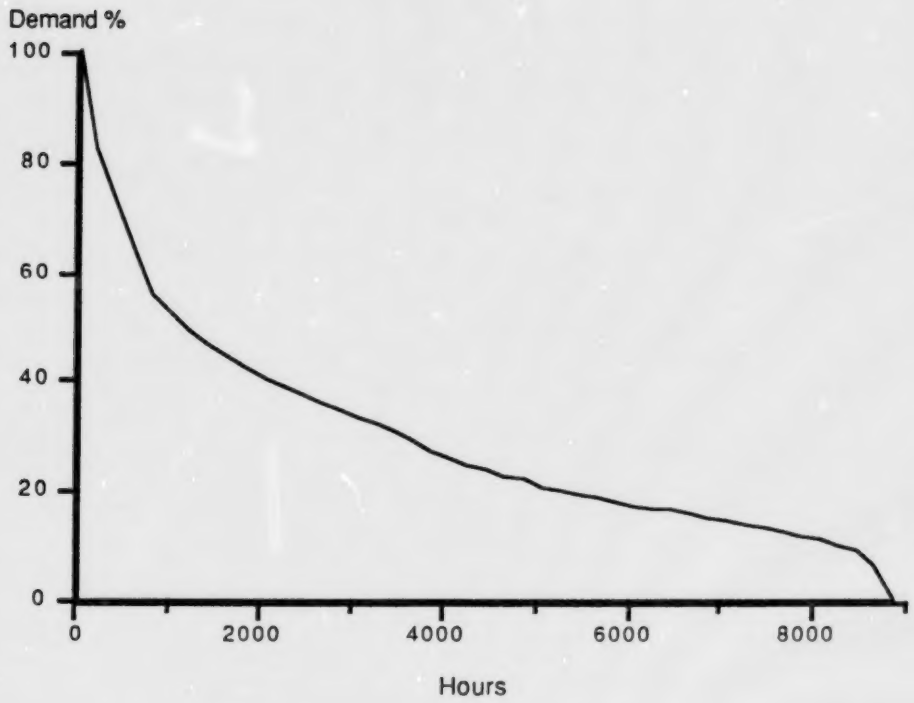
Heat only boiler plants for hot water DH are usually hot water boilers ranging in size up to several hundred MW. Small boilers are separated from the system through heat exchangers. The flue gas temperatures are cooled to approximately 200^{o}C by using air preheaters and DH economizers.

When burning low-sulphur fuels, such as wood-chips, the flue gases can be cooled to below 100^{o}C without condensation taking place. Because low temperature heat can be utilized, condensation of flue gases is more and more common as a means of both increasing efficiency and reducing emissions. For example, the 3 x 120 MW hot water coal fired plant at Igelsta, Sweden, features 70^{o}C flue gases after desulphurization (and reheating to get the gases out through the stack).

In intermediate temperature district heating systems, the flue gas can be cooled and condensed in gas condensers. This approach decreases harmful emissions and increases the efficiency of the system further. Spray-recuperators are also being used when feasible.

Hot water DH systems offer good opportunities for cogeneration in thermal plants. With water temperatures in

Figure A.2.5



Load Duration Curve for District Heating System

the range of 70-90°C at the cogeneration plant, the power yield is adequate and the combination of heat and power production enhances the economic viability of both DH and electricity production in thermal plants. Cogeneration can also contribute to an increase in the consumption of locally available fuels such as wood waste.

In order to justify a cogeneration plant of reasonable capacity, the district heating system must be large in order to provide adequate condenser cooling. For example, a 100 MWth peak demand system may justify a 35 MWth base load cogeneration plant, which will produce 10 MWel of electricity.

Low temperature heat sources such as heat pumps and internal combustion engine cooling systems work well with hot water DH systems. These systems can be utilized as long as the available capacity is sized for the base load, even if the peak supply temperature of the DH system after the peaking boilers is high. However, the return temperature must be kept as low as possible to maximize the utilization and efficiency of the low temperature heat source.

2.6 Operation and Maintenance of Hot Water Systems

The operation of the hot water system is usually fully automatic once the system is started up and does not require any dedicated staff. Only in very large systems are operators required to optimize production at different plants and to operate pumping stations.

The substations are usually checked every one to three months when the heat meters are read (if this is not done through remote readings). Most modern hot water DH systems are built as economically as possible, using directly buried, thinwall carrier pipe and other low cost equipment alternatives. Periodic preventative maintenance is therefore required to check the performance of the system.

Preventative maintenance should be carried out through a regular check of remotely controlled pumping stations, valves in chambers, vents and drains.

All equipment inside the production plant is usually maintained by the plant personnel. Hot water boiler plants for DH usually require fewer staff in Europe than in Canada because of code differences and advanced computerized control systems. In Sweden, many operator functions are centralized in the control room and the boilers are highly automated. For example, the Sandviken Plant (2 x 15 MW fluidized bed, peat + 125 MW oil) is staffed by 3 men (operating and

maintenance) during the day and one man at night.

The water in the DH system should be treated to prevent corrosion. Because the system is a closed loop, the amount and cost of chemicals used after start-up is low. The DH water is usually:

1) Softened;
2) De-aerated (mechanically or chemically);
3) pH-adjusted;
4) Mechanically filtered.

The amount of water added to the system is continuously monitored.

The technical/economical life of hot water systems is approximately 20-30 years. However, many older systems are in good shape and have a much longer expected life. Experience with small institutional systems without water treatment and regular maintenance varies. Some systems work very well while other systems show problems with corrosion after only a few years operation.

2.7 Availability of Technology

Hot water DH systems have been used extensively in Europe since World War II. Suitable technologies and products have been developed specifically for DH applications. These products and technologies have been proven through theoretical analysis as well as actual applications. Viable solutions to problems have been used in DH applications for many years.

When DH was revitalized in the United States during the last decade, many systems were code exempt for various reasons and suitable products were purchased without difficulty. Many of the DH products used were of European origin. Most European products are manufactured in accordance with national codes and/or comply with the West German code, DIN.

At the time of this report, products such as meters and ball valves designed for hot water DH applications were not readily available in Canada at competitive prices. By late 1987, however, considerable progress had been made towards obtaining products and code approval for products such as welded ball valves, low cost heat metres, brazed or welded heat exchangers for district heating and suitable electronic controls.

Despite some of the problems mentioned above, it is possible to build and operate hot water DH systems in Canada at

reasonable cost. For example, the total installed cost including double, preinsulated piping, valves, trenching, backfilling and reinstatement was approximately $250-$600 per metre for sizes Dia 50mm - Dia 250mm in a medium sized city.

APPENDIX 3

Piping and Substation Costing

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Piping and Substation Costing

Capital costs were developed by the project team for the two applications examined: Charlottetown and McMaster University.

The costs were based on slightly high material costs and lower productivity on P.E.I. However, these factors were offset by lower labour costs. The total labour cost and total installed cost were therefore judged to be approximately equal in P.E.I. and Ontario.

The Charlottetown site was the downtown core of a small city. The McMaster site was a large university in Hamilton, Ontario. Both sites were judged to have medium complexity. Installation costs for piping would be substantially lower in a rural area and much higher in the downtown core of a large city.

The costs were based on:

Hot Water

1) Preinsulated thinwall steel pipes with polyurethane (PUR) foam insulation and polyethylane (PEH) casing;

2) Parallel substations. In an actual design, some substations would have parallel or 2-stage couplings.

Steam

1) Steel pipes (Schedule 40) with fibreglass insulation, sheet metal cover, poured in concrete with bituminous coating and directly buried;

2) Substation consisting of:

    * reducing station
    * heat exchanger
    * secondary DHW (existing)
    * traps, condensate tank, condensate pumps
    * condensate flowmeter (steam meter would increase the cost)
    * secondary mixing valve

3) Cost figures were also developed for the replacement of existing steam pipes in tunnels.

The methods for piping selected by the team were:

Charlottetown

1) Steam - directly buried piping cast in concrete

2) Hot Water - directly buried preinsulated piping

McMaster

1) Steam - tunnel sections: replacement
- directly buried sections: new directly buried piping cast in concrete

2) Hot Water - the whole system was assumed to be replaced with a new directly buried system outside the tunnels.

Costs were developed by AFE Engineering Inc. (AFE) and Maunder and Britnell Engineering Ltd. (M&B) as the average for Charlottetown and McMaster and include manholes, valves, pavement, traffic bridges, trucking away all excess soil, etc.

The piping costs are summarized in Table A3.1. Substation costs are summarized in Table A3.2.

Table A3.1

Installed Piping Costs

Hot Water Piping		Steam Piping Steam/Condensate		Steam-Replacement in tunnels	
Size	$/m trench	Size	$/m trench	Size	$/m tunnel
28 mm	$250	25/25mm	$ 450	25/25mm	$ 300
32	260	38/25	480	38/25	320
40	270	50/25	500	50/25	340
50	280	75/55	560	75/55	420
65	300	100/55	640	100/55	500
80	330	150/75	750	150/75	620
100	350	200/100	920	200/100	850
125	380	250/150	1100	250/150	1050
150	400				
200	500				
250	600				
300	700				

Priced by AFE and M&B, 1987 $.

Table A3.2

Substations Costs

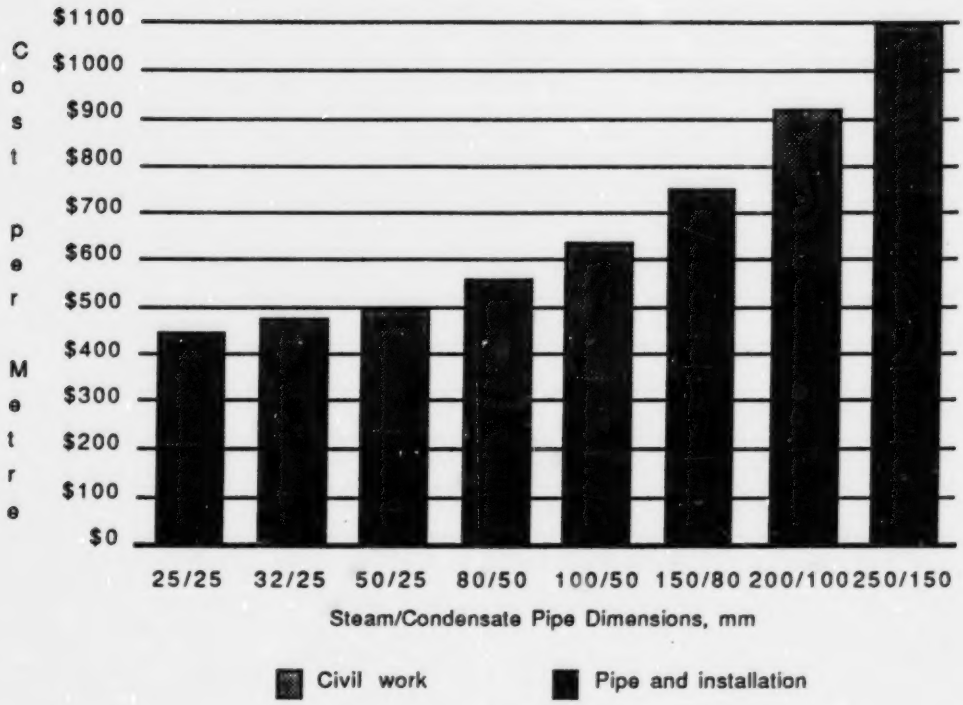
HW - parallel connection
Steam - St/HW heat exchanger

Peak	
<50 kw	$13,200
50-500 kw	13,200 + 40/kw
>500 kw	20,500 + 26/kw

Same price for hot water and steam

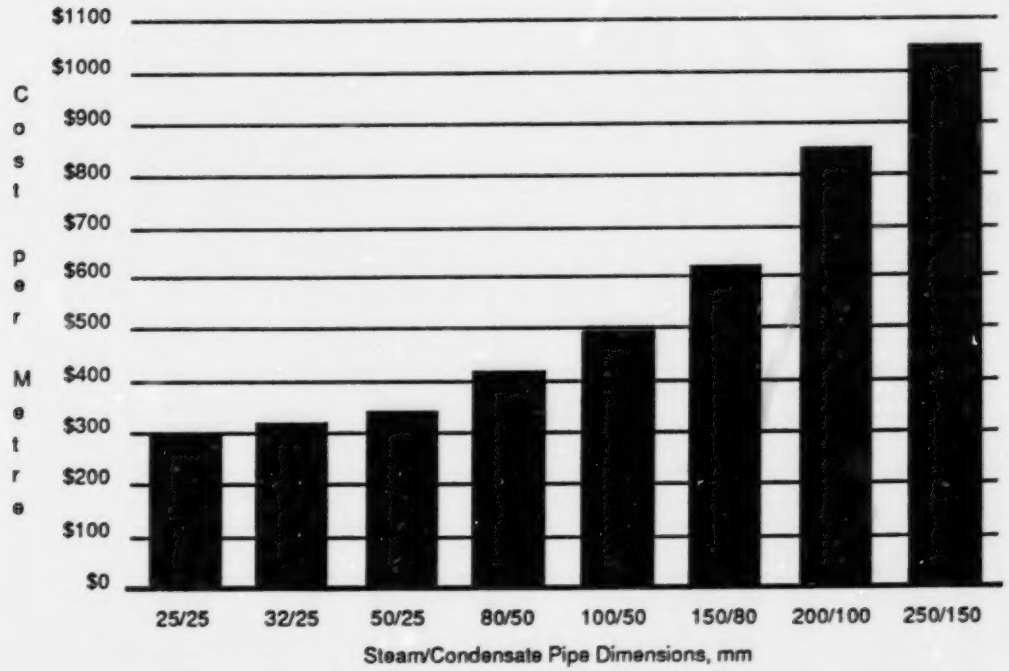
Priced by AFE and M&B, 1987 $.

Figure A.3.1



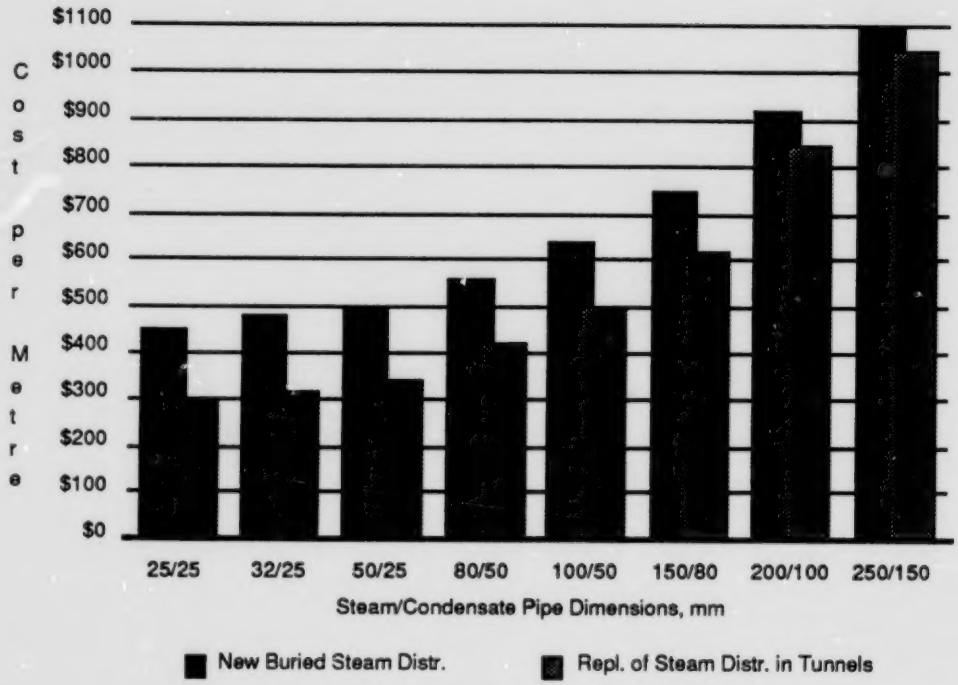
Steam Distribution
Cost per Metre

Figure A.3.2



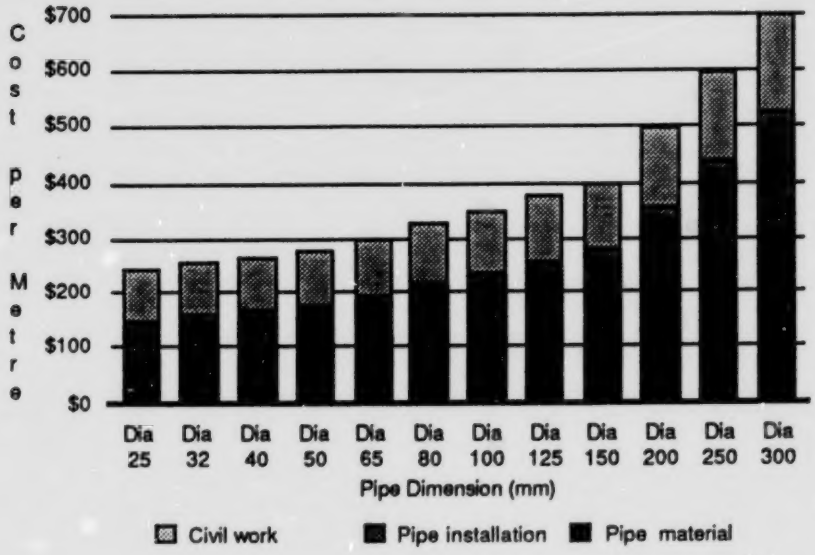
Steam Distribution in Tunnels
Replacement Cost per Metre

Figure A.3.3



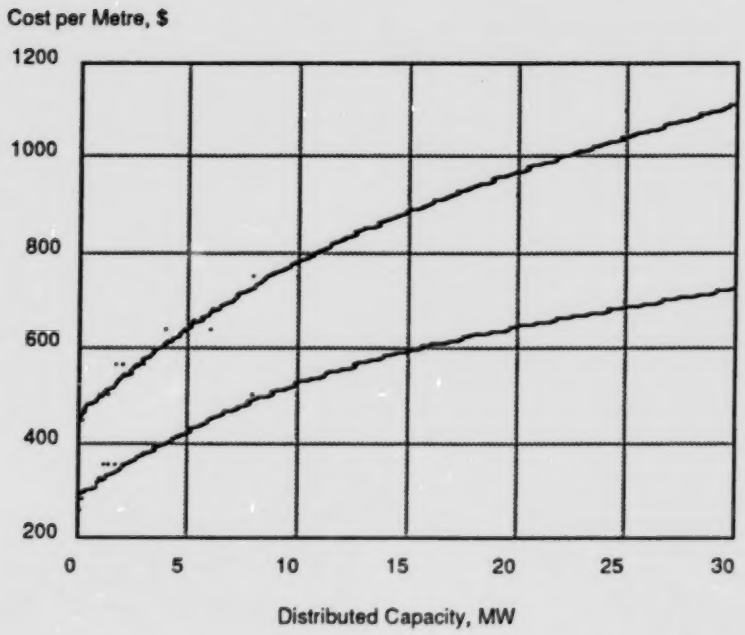
Cost Comparison for Steam Distribution

Figure A.3.4



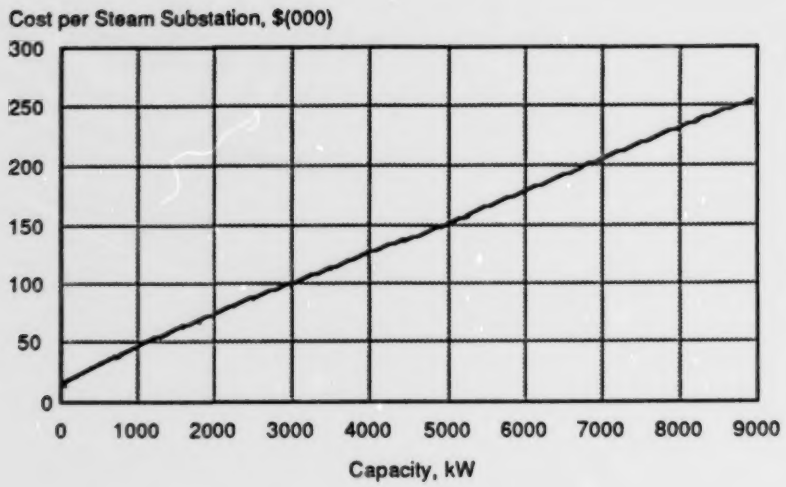
Hot Water Distribution
Cost per Metre

Figure A.3.5



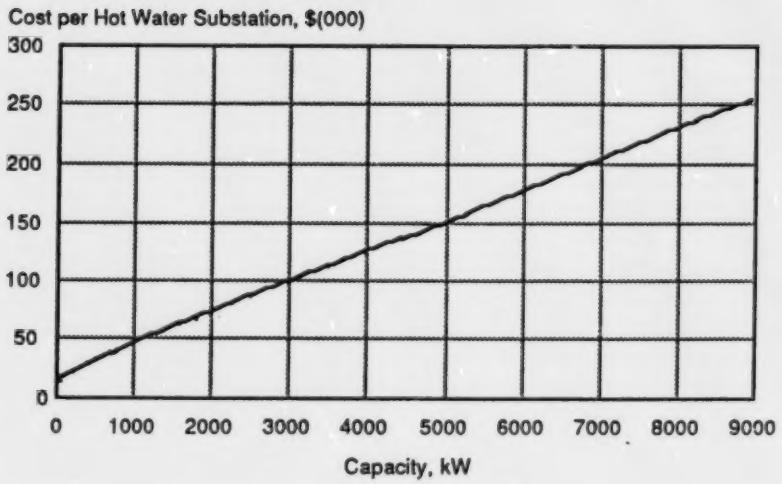
Comparison of Steam/Hot Water Distribution Costs per MW

Figure A.3.6



Cost of Substations
Steam

Figure A.3.7



Cost of Substations
Hot Water

APPENDIX 4

Technical Data for Case Studies

APPENDIX 4

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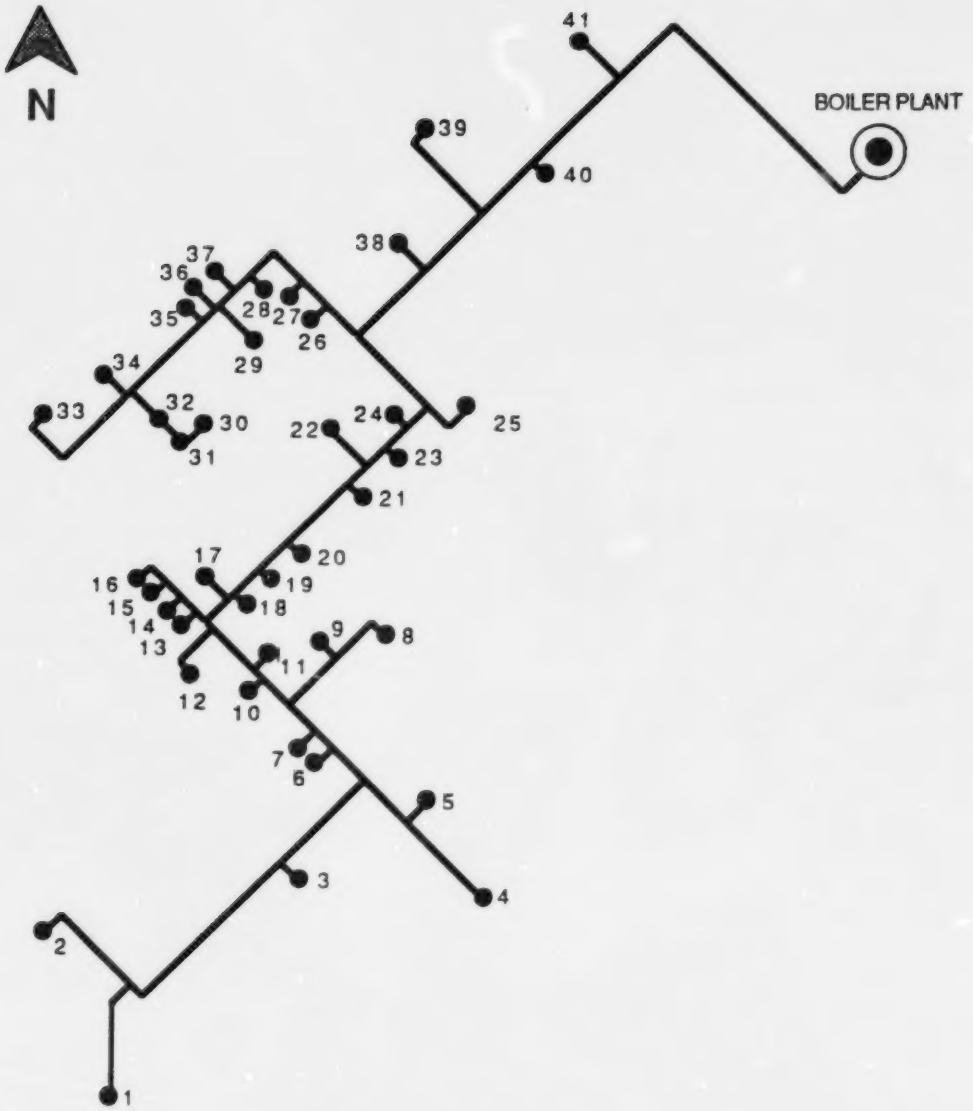
A4.1 Charlottetown Case Study

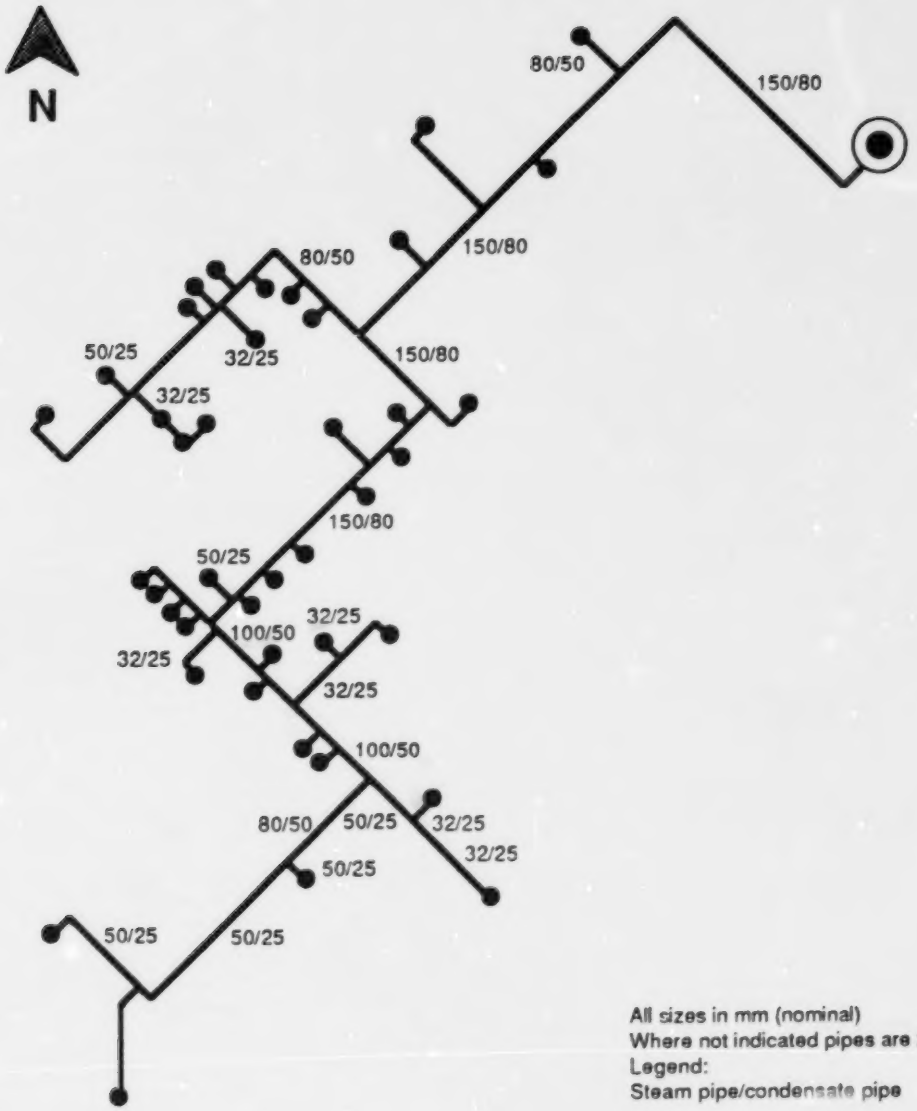
Technical Data

Figure A.4.1



Charlottetown
District Heating System
Layout and Subscribers

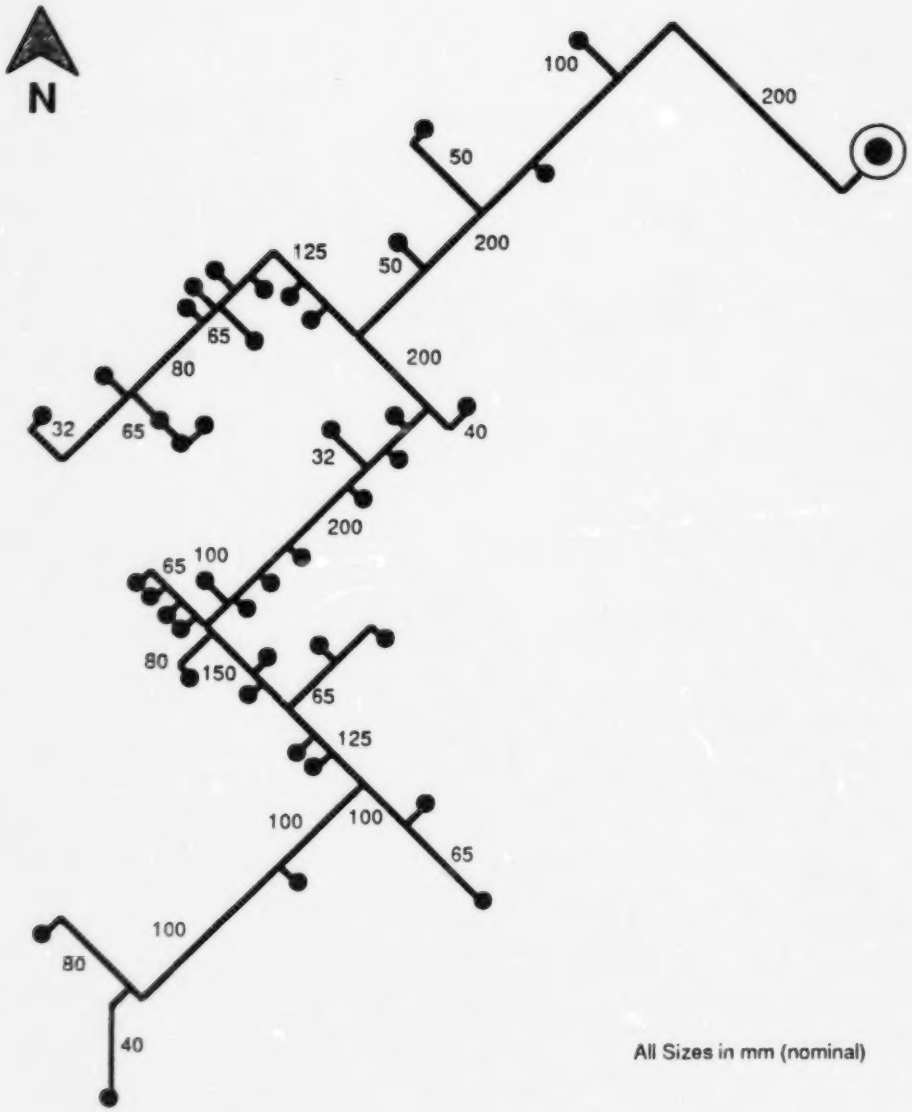
Figure A.4.2



All sizes in mm (nominal)
Where not indicated pipes are 25/25
Legend:
Steam pipe/condensate pipe

Charlottetown
District Heating System
Pipe Sizes - Steam

Figure A.4.3



All Sizes in mm (nominal)

Charlottetown
District Heating System
Pipe Sizes - Hot Water

Table A.4.1 Charlottetown District Heating System - Subscribers

Site	Peak-kW	Peak-Btu/hr	Steam-lb/hr	HW flow-kg/s
1	132	450,516	542	0.79
2 Steam	1,200	4,095,600	4,928	
2 Hot Water	960	3,276,480		5.73
3	1,000	3,413,000	4,107	5.97
4	475	1,621,175	1,951	2.83
5	702	2,395,926	2,883	4.19
6	53	180,889	218	0.32
7	181	617,753	743	1.08
8	112	382,256	460	0.67
9	475	1,621,175	1,951	2.83
10	56	191,128	230	0.33
11	93	317,409	382	0.55
12	732	2,498,316	3,006	4.37
13	122	416,386	501	0.73
14	66	225,258	271	0.39
15	72	245,736	296	0.43
16	78	266,214	320	0.47
17	1,157	3,948,841	4,751	6.90
18	59	201,367	242	0.35
19	101	344,713	415	0.60
20	145	494,885	595	0.87
21	48	163,824	197	0.29
22	84	286,692	345	0.50
23	157	535,841	645	0.94
24	137	467,581	563	0.82
25	132	450,516	542	0.79
26	55	187,715	226	0.33
27	108	368,604	444	0.64
28	168	573,384	690	1.00
29	523	1,784,999	2,148	3.12
30	56	191,128	230	0.33
31	135	460,755	554	0.81
32	508	1,733,804	2,086	3.03
33	101	344,713	415	0.60
34	129	440,277	530	0.77
35	126	430,038	517	0.75
36	156	532,428	641	0.93
37	98	334,474	402	0.58
38	300	1,023,900	1,232	1.79
39 Steam	500	1,706,500	2,053	
39 Hot Water	300	1,023,900		1.79
40	155	529,015	637	0.92
41	2,000	6,826,000	8,213	11.93

Table A.4.2 Charlottetown Steam Distribution Costing

From	To	Flow lb/hr	Steam Pipe mm	Condensate Pipe mm	Pipe length metre	Cost/metre $/metre	Cost $
Site 1	1	544	25.00	25.00	91	450	40,950
Site 2	1	4,928	50.00	25.00	127	500	63,500
1	2	5,472	50.00	25.00	200	500	100,000
Site 3	2	4,109	50.00	25.00	25	500	12,500
2	4	9,580	80.00	50.00	112	560	62,720
Site 4	3	1,948	32.00	25.00	119	480	57,120
Site 5	3	2,884	50.00	25.00	30	480	14,400
3	4	4,832	50.00	25.00	62	500	31,000
Site 6	Main	220	25.00	25.00	20	450	9,000
Site 7	Main	743	25.00	25.00	20	450	9,000
4	6	15,376	100.00	50.00	131	640	83,840
Site 8	5	461	25.00	25.00	62	450	27,900
Site 9	5	1,948	32.00	25.00	20	480	9,600
5	6	2,409	32.00	25.00	69	480	33,120
Site 10	Main	227	25.00	25.00	25	450	11,250
Site 11	Main	379	25.00	25.00	20	450	9,000
Site 12	Main	3,008	32.00	25.00	70	480	33,600
6	8	21,398	100.00	50.00	123	640	78,720
Site 16	7	323	25.00	25.00	15	450	6,750
Site 15	Main	296	25.00	25.00	15	450	6,750
Site 14	Main	268	25.00	25.00	15	450	6,750
Site 13	Main	544	25.00	25.00	15	450	6,750
7	8	1,390	25.00	25.00	59	450	26,550
Site 17	Main	4,749	50.00	25.00	30	500	15,000
Site 18	Main	241	25.00	25.00	15	450	6,750
Site 19	Main	413	25.00	25.00	15	450	6,750
Site 20	Main	599	25.00	25.00	15	450	6,750
Site 21	Main	200	25.00	25.00	15	450	6,750
Site 22	Main	344	25.00	25.00	43	450	19,350
Site 23	Main	647	25.00	25.00	15	450	6,750
Site 24	Main	564	25.00	25.00	20	450	9,000
8	9	30,545	150.00	80.00	317	750	237,750
Site 25	9	544	25.00	25.00	61	450	27,450
9	12	31,089	150.00	80.00	112	750	84,000

Table A.4.2 Charlottetown Steam Distribution Costing

Site 33	10	413	25.00	25.00	129	450	58,050
Site 30	Site 31	227	25.00	25.00	28	450	12,600
Site 31	Site 32	785	25.00	25.00	31	450	13,950
Site 32	10	2,870	32.00	25.00	48	480	23,040
Site 34	10	530	25.00	25.00	20	450	9,000
Site 35	Main	516	25.00	25.00	15	450	6,750
Site 36	11	640	25.00	25.00	25	450	11,250
Site 29	11	2,147	32.00	25.00	68	480	32,640
10	11	4,329	50.00	25.00	138	500	69,000
Site 37	Main	399	25.00	25.00	25	450	11,250
Site 28	Main	688	25.00	25.00	15	450	6,750
Site 27	Main	440	25.00	25.00	18	450	8,100
Site 26	Main	227	25.00	25.00	18	450	8,100
11	12	8,872	80.00	50.00	210	560	117,600
Site 38	Main	1,232	25.00	25.00	27	450	12,150
Site 39	Main	2,053	25.00	25.00	119	450	53,550
Site 40	Main	633	25.00	25.00	20	450	9,000
12	13	43,879	150.00	80.00	380	750	285,000
Site 41	13	8,211	80.00	50.00	52	560	29,120
13	Boiler Plant	52,090	150.00	80.00	377	750	282,750
TOTAL					**3,866**		**2,226,720**

Table A.4.3 Charlottetown Hot Water Distribution Costing

From	To	Flow kg/s	Pipe size Dia	Pipe length metre	Relative pressure loss mbar/m	Pressure loss Bar	Cost/metre $/metre	Cost $
Site 1	1	0.79	40	91	1.25	0.23	270	24,570
Site 2	1	5.73	80	127	1.60	0.41	330	41,910
1	2	6.52	100	200	0.60	0.24	350	70,000
Site 3	2	5.97	80	25	1.90	0.10	330	8,250
2	4	12.49	100	112	2.00	0.45	350	39,200
Site 4	3	2.83	65	119	1.00	0.24	300	35,700
Site 5	3	4.19	65	30	2.00	0.12	300	9,000
3	4	7.02	100	62	0.65	0.08	350	21,700
Site 6	Main	0.32	25	20	2.00	0.08	250	5,000
Site 7	Main	1.08	40	20	2.00	0.08	270	5,400
4	6	20.91	125	131	1.85	0.48	380	49,780
Site 8	5	0.67	32	62	1.85	0.23	260	16,120
Site 9	5	2.83	65	20	1.00	0.04	300	6,000
5	6	3.50	65	69	1.45	0.20	300	20,700
Site 10	Main	0.33	25	25	2.00	0.10	250	6,250
Site 11	Main	0.55	32	20	1.30	0.05	260	5,200
Site 12	Main	4.37	80	70	1.00	0.14	330	23,100
6	8	29.66	150	123	1.40	0.34	400	49,200
Site 16	7	0.47	32	15	0.90	0.03	260	3,900
Site 15	Main	0.43	32	15	0.85	0.03	260	3,900
Site 14	Main	0.39	32	15	0.70	0.02	260	3,900
Site 13	Main	0.79	40	15	1.15	0.03	270	4,050
7	8	2.02	65	59	0.50	0.06	300	17,700
Site 17	Main	6.90	100	30	0.65	0.04	350	10,500
Site 18	Main	0.35	32	15	0.60	0.02	260	3,900
Site 19	Main	0.60	32	15	1.50	0.05	260	3,900
Site 20	Main	0.87	40	15	1.45	0.04	270	4,050
Site 21	Main	0.29	25	15	1.55	0.05	250	3,750
Site 22	Main	0.50	32	43	1.10	0.09	260	11,180
Site 23	Main	0.94	40	15	1.70	0.05	270	4,050
Site 24	Main	0.82	40	20	1.30	0.05	270	5,400
8	9	42.95	200	317	0.75	0.48	500	158,500
Site 25	9	0.79	40	61	1.20	0.15	270	16,470

Table A.4.3 Charlottetown Hot Water Distribution Costing

9	12	43.74	200	112	0.80	0.18	400	44,800
Site 33	10	0.60	32	129	1.50	0.39	260	33,540
Site 30	Site 31	0.33	25	28	2.00	0.11	250	7,000
Site 31	Site 32	1.14	50	31	0.75	0.05	280	8,680
Site 32	10	4.17	65	48	2.00	0.19	300	14,400
Site 34	10	0.77	40	20	1.15	0.05	270	5,400
Site 35	Main	0.75	40	15	1.10	0.03	270	4,050
Site 36	11	0.93	40	25	1.60	0.08	270	6,750
Site 29	11	3.12	65	68	1.20	0.16	300	20,400
10	11	6.29	80	138	2.00	0.55	330	45,540
Site 37	Main	0.58	32	25	1.45	0.07	260	6,500
Site 28	Main	1.00	40	15	1.90	0.06	270	4,050
Site 27	Main	0.64	32	18	1.75	0.06	260	4,680
Site 26	Main	0.33	25	18	2.00	0.07	250	4,500
11	12	12.89	125	210	0.75	0.32	380	79,800
Site 38	Main	1.79	50	27	1.75	0.09	280	7,560
Site 39	Main	1.79	50	119	1.75	0.42	280	33,320
Site 40	Main	0.92	40	20	1.65	0.07	270	5,400
12	13	61.13	200	380	1.50	1.14	400	152,000
Site 41	13	11.93	100	52	1.90	0.20	350	18,200
13	Boiler Plant	73.06	200	377	2.10	1.58	400	150,800
TOTAL				**3,866**				**1,349,600**

Table A.4.4 Charlottetown District Heating System - Steam Substations

Site	Peak-kW	Comment	Substation $
1	132		18,480
2	1,200	Steam supply	30,000
3	1,000		46,500
4	475		32,200
5	702		38,752
6	53		15,320
7	181		20,440
8	112		17,680
9	475		32,200
10	56		15,440
11	93		16,920
12	732	Steam supply	25,000
13	122		18,080
14	66		15,840
15	72		16,080
16	78		16,320
17	1,157		50,582
18	59		15,560
19	101		17,240
20	145		19,000
21	48		13,200
22	84		16,560
23	157		19,480
24	137		18,680
25	132		18,480
26	55		15,400
27	108		17,520
28	168		19,920
29	523		34,098
30	56		15,440
31	135		18,600
32	508		33,708
33	101		17,240
34	129		18,360
35	126		18,240
36	156		19,440
37	98		17,120
38	300		25,200
39	500	Steam supply	25,000
40	155		19,400
41	1,999		72,500
TOTAL	12,683		951,220

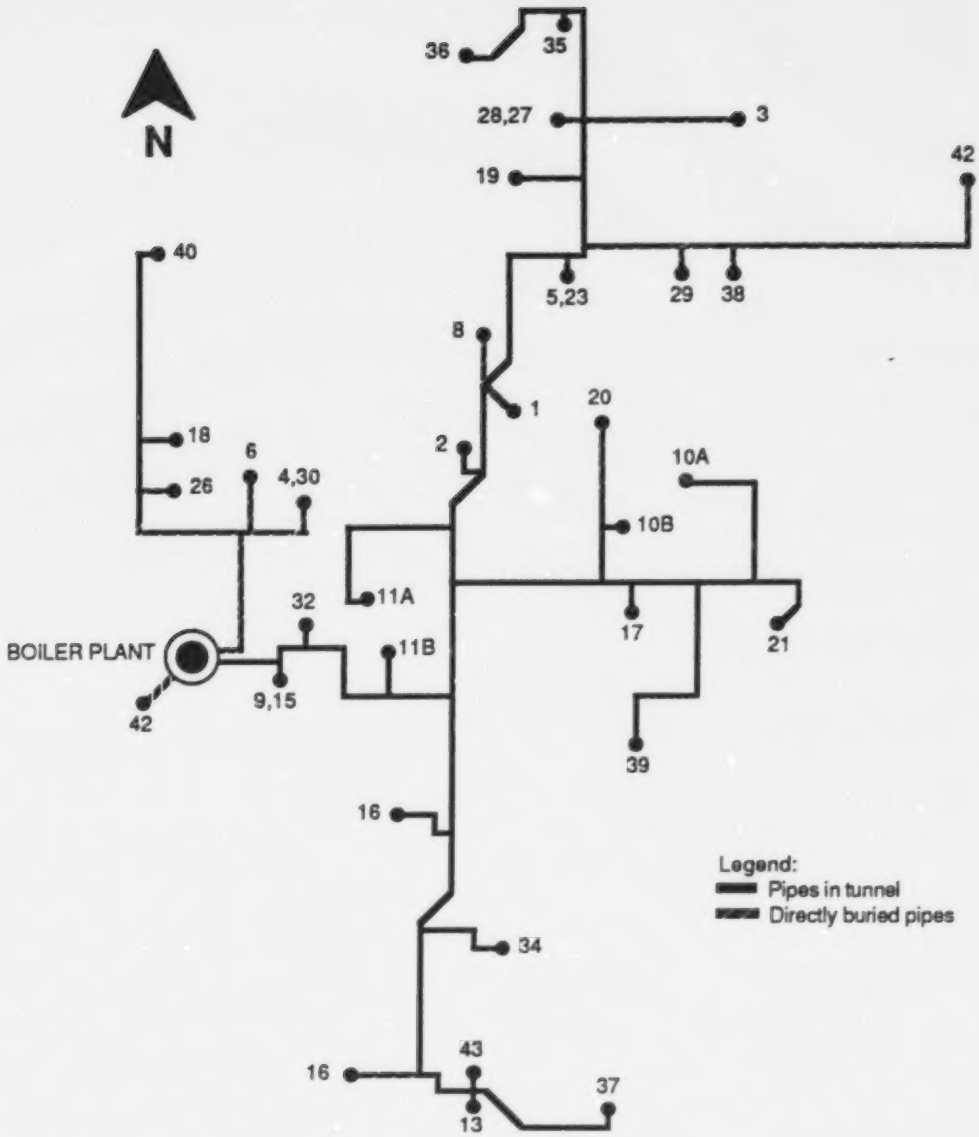
Table A.4.5 Charlottetown District Heating System - Hot Water Substations

Site	Peak-kW	Comment	Substation $
1	132		18,480
2	960	$ 40,000 extra	85,460
3	1,000		46,500
4	475		32,200
5	702		38,752
6	53		15,320
7	181		20,440
8	112		17,680
9	475		32,200
10	56		15,440
11	93		16,920
12	732	Steam conversion	139,532
13	122		18,080
14	66		15,840
15	72		16,080
16	78		16,320
17	1,157		50,582
18	59		15,560
19	101		17,240
20	145		19,000
21	48		13,200
22	84		16,560
23	157		19,480
24	137		18,680
25	132		18,480
26	55		15,400
27	108		17,520
28	168		19,920
29	523		34,098
30	56		15,440
31	135		18,600
32	508		33,708
33	101		17,240
34	129		18,360
35	126		18,240
36	156		19,440
37	98		17,120
38	300		25,200
39	300		25,200
40	155		19,400
41	2,000		72,500
TOTAL	**12,247**		**1,121,412**

A4.2 McMaster Case Study

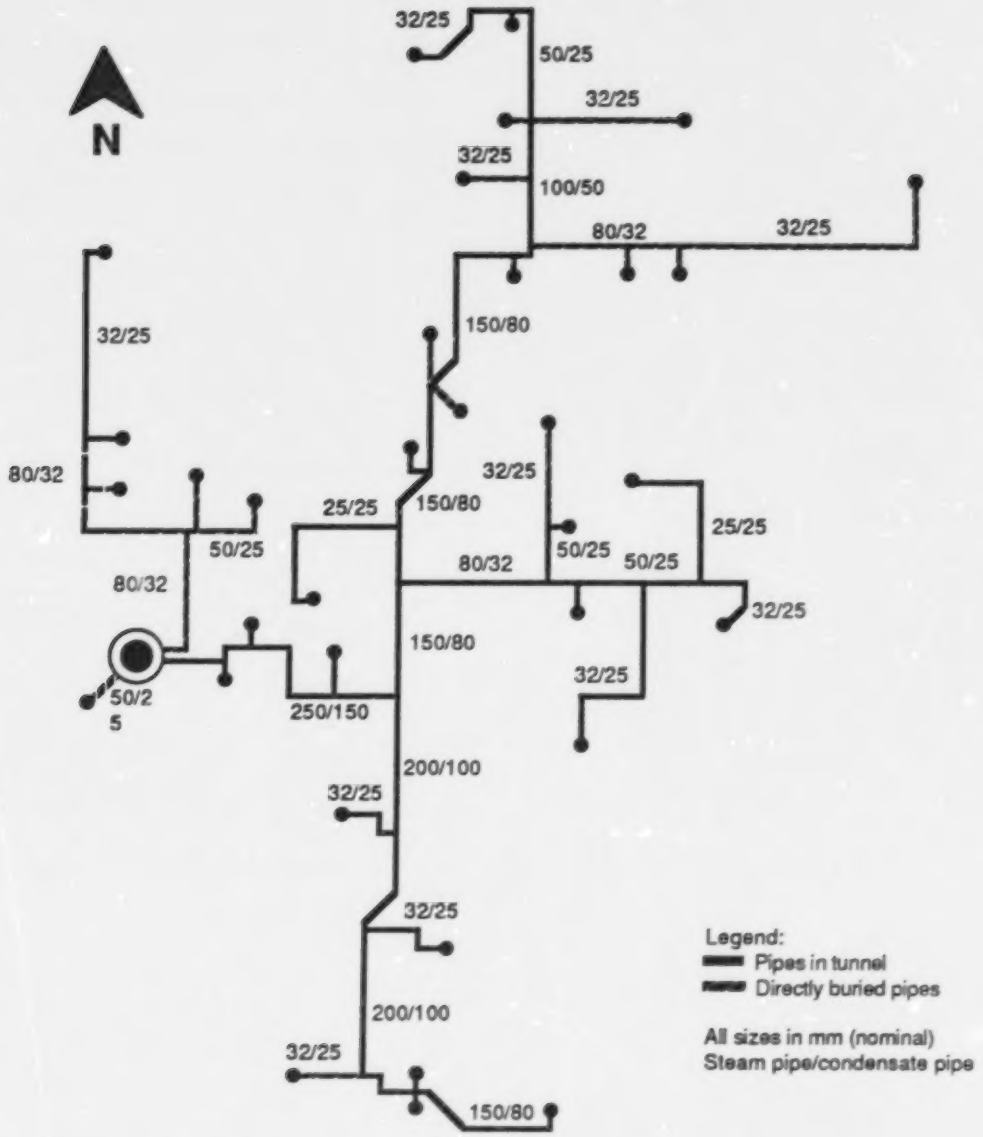
Technical Data

Figure A.4.4



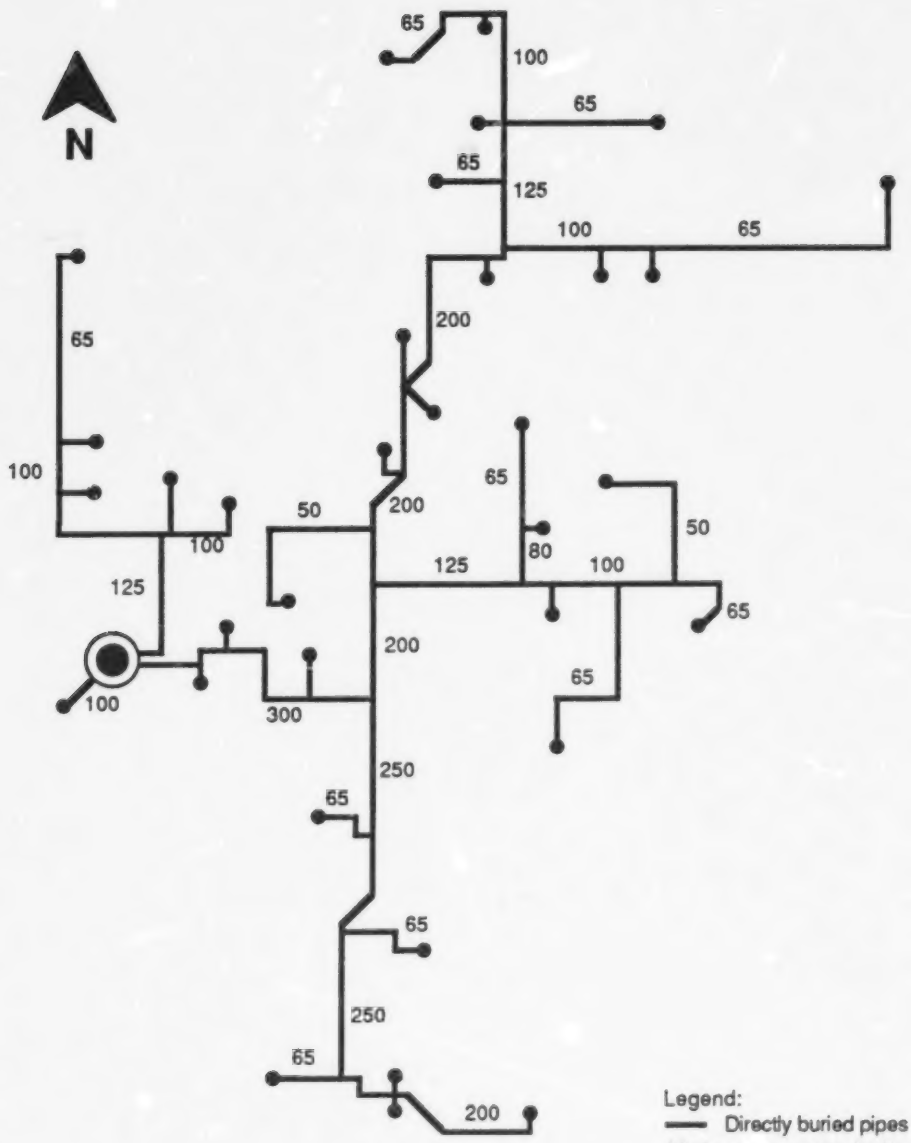
McMaster University
District Heating System
Layout and Subscribers

Figure A.4.5



McMaster University
District Heating System
Pipe Sizes Steam

Figure A.4.6



McMaster University
District Heating System
Pipe Sizes - Hot Water

McTable A.4.6 Master University District Heating System - Subscribers

Site	Peak-kW	Peak-Btu/hr	Steam-lb/hr	HW flow-kg/s
36	617	2,107,500	2,500	3.68
35	617	2,107,500	2,500	3.68
27&28	1,235	4,215,000	5,000	7.37
3	617	2,107,500	2,500	3.68
19	617	2,107,500	2,500	3.68
24	617	2,107,500	2,500	3.68
38	617	2,107,500	2,500	3.68
29	617	2,107,500	2,500	3.68
5&23	1,235	4,215,000	5,000	7.37
1	617	2,107,500	2,500	3.68
8	617	2,107,500	2,500	3.68
2	617	2,107,500	2,500	3.68
11A	309	1,053,750	1,250	1.84
21	617	2,107,500	2,500	3.68
10A	309	1,053,750	1,250	1.84
39	617	2,107,500	2,500	3.68
17	617	2,107,500	2,500	3.68
20	617	2,107,500	2,500	3.68
10B	309	1,053,750	1,250	1.84
11B	309	1,053,750	1,250	1.84
22&32	1,235	4,215,000	5,000	7.37
9&15	1,235	4,215,000	5,000	7.37
42&25	1,235	4,215,000	5,000	7.37
40	617	2,107,500	2,500	3.68
18	617	2,107,500	2,500	3.68
26	617	2,107,500	2,500	3.68
6	617	2,107,500	2,500	3.68
4&30	1,235	4,215,000	5,000	7.37
37 Steam	11,115	37,935,000	45,000	
37 Hot Water	10,374	35,406,000		61.90
43	617	2,107,500	2,500	3.68
13	617	2,107,500	2,500	3.68
16	617	2,107,500	2,500	3.68
34	617	2,107,500	2,500	3.68
44	617	2,107,500	2,500	3.68

Table A.4.7 McMaster University Steam Distribution Costing

From	To	Flow lb/hr	Steam Pipe mm	Condensate Pipe mm	Pipe length metre	Replacement in tunnel	Buried Piping	Cost/metre $/metre	Cost $
Site 40	1	2,497	32	25	132	x		320	42,240
Site 18	1	2,497	32	25	24	x		320	7,680
Site 26	Main	2,497	32	25	20		x	480	9,600
1	2	7,491	80	32	156	0.50	0.50	490	76,440
Site 4,30	2	4,994	50	25	65		x	500	32,500
Site 6	Main	2,036	32	25	34		x	480	16,320
2	3	12,485	80	32	102		x	560	57,120
Site 36	4	2,497	32	25	81	x		320	25,920
Site 35	4	2,497	32	25	10	x		320	3,200
4	5	4,994	50	25	104	x		340	35,360
Site 28,27	5	4,994	50	25	10		x	500	5,000
Site 3	5	2,497	32	25	110		x	480	52,800
Site 19	Main	2,497	32	25	40		x	480	19,200
5	7	14,982	100	50	94	x		500	47,000
Site 42	6	2,497	32	25	116		x	480	55,680
Site 38	6	2,497	32	25	20		x	480	9,600
Site 29	Main	2,497	32	25	35		x	480	16,800
6	7	7,491	80	32	120		x	560	67,200
Site 5, 23	Main	4,994	50	25	14		x	500	7,000
7	8	27,468	150	80	172	x		620	106,640
Site 8	8	2,497	32	25	32		x	480	15,360
Site 1	8	2,497	32	25	24		x	480	11,520
Site 2	Main	2,497	32	25	24	x		320	7,680
Site 11A	Main	1,249	25	25	140	x		300	42,000
Site 21	9	2,497	32	25	80	x		320	25,600
Site 10A	9	1,249	25	25	123	x		300	36,900
Site 39	Main	2,497	32	25	164	x		320	52,480
9	10	6,243	50	25	96	x		340	32,640
Site 17	10	2,497	32	25	25	x		320	8,000
Site 20	11	2,497	32	25	78	0.20	0.80	448	34,944
Site 10B	11	1,249	25	25	10	x		300	3,000
11	Main	3,746	50	25	40	x		340	13,600
10	Main	12,485	80	32	136	x		420	57,120
8	13	48,693	150	80	247	x		620	153,140

Table A.4.7 McMaster University Steam Distribution Costing

Site 37	12	45,002	150	80	123	x		620	76,260
Site 43	12	2,497	32	25	10	x		320	3,200
Site 13	12	2,497	32	25	5	x		320	1,600
Site 16	Main	2,497	32	25	46		x	480	22,080
Site 34	Main	2,497	32	25	70	x		320	22,400
Site 16	Main	2,497	32	25	40	x		320	12,800
12	13	54,488	200	100	342	x		850	290,700
Site 11B	Main	1,249	25	25	30	x		300	9,000
Site 32	Main	2,497	25	25	15	x		320	4,800
Site 9,15	Main	4,994	25	25	10	x		340	3,400
13	3	103,181	250	150	207	x		1,050	217,350
Site 42,25	3	4,994	50	25	36		x	500	18,000
TOTAL					**3,612**				**1,868,874**

Table A.4.8 McMaster University Hot Water Distribution Costing

From	To	Flow kg/s	Pipe size Dia	Pipe length metre	Relative pressure loss mbar/m	Pressure loss Bar	Cost/metre $/metre	Cost $
Site 40	1	3.68	65	132	1.62	0.21	300	39,600
Site 18	1	3.68	65	24	1.62	0.04	300	7,200
Site 26	Main	3.68	65	20	1.62	0.03	300	6,000
1	2	11.04	100	156	1.56	0.24	350	54,600
Site 4,30	2	7.36	100	65	0.72	0.05	350	22,750
Site 6	Main	3.00	65	34	1.62	0.06	300	10,200
2	3	18.40	125	102	1.50	0.15	380	38,760
Site 36	4	3.68	65	81	1.62	0.13	300	24,300
Site 35	4	3.68	65	10	1.62	0.02	300	3,000
4	5	7.36	100	104	0.72	0.07	350	36,400
Site 28,27	5	7.36	100	10	0.72	0.01	350	3,500
Site 3	5	3.68	65	110	1.62	0.18	300	33,000
Site 19	Main	3.68	65	40	1.62	0.06	300	12,000
5	7	22.08	125	94	2.10	0.20	380	35,720
Site 42	6	3.68	65	116	1.62	0.19	300	34,800
Site 38	6	3.68	65	20	1.62	0.03	300	6,000
Site 29	Main	3.68	65	35	1.62	0.06	300	10,500
6	7	11.04	100	120	1.56	0.19	350	42,000
Site 5, 23	Main	7.36	100	14	0.72	0.01	350	4,900
7	8	40.48	200	172	0.69	0.12	500	86,000
Site 8	8	3.68	65	32	1.62	0.05	300	9,600
Site 1	8	3.68	65	24	1.62	0.04	300	7,200
Site 2	Main	3.68	65	24	1.62	0.04	300	7,200
Site 11A	Main	1.84	50	140	1.80	0.25	280	39,200
Site 21	9	3.68	65	80	1.62	0.13	300	24,000
Site 10A	9	1.84	50	123	1.80	0.22	280	34,440
Site 39	Main	3.68	65	164	1.62	0.27	300	49,200
9	10	9.20	100	96	1.13	0.11	350	33,600
Site 17	10	3.68	65	25	1.62	0.04	300	7,500
Site 20	11	3.68	65	78	1.62	0.13	300	23,400
Site 10B	11	1.84	50	10	1.80	0.02	280	2,800
11	Main	5.52	80	40	1.56	0.06	330	13,200
10	Main	18.40	125	136	1.50	0.20	380	51,680

Table A.4.8 McMaster University Hot Water Distribution Costing

8	13	71.76	200	247	2.00	0.49	500	123,500
Site 37	12	61.90	200	123	1.56	0.19	500	61,500
Site 43	12	3.68	65	10	1.62	0.02	300	3,000
Site 13	12	3.68	65	5	1.62	0.01	300	1,500
Site 16	Main	3.68	65	46	1.62	0.07	300	13,800
Site 34	Main	3.68	65	70	1.62	0.11	300	21,000
Site 16	Main	3.68	65	40	1.62	0.06	300	12,000
12	13	80.30	250	342	0.79	0.27	600	205,200
Site 11B	Main	1.84	50	30	1.80	0.05	280	8,400
Site 32	Main	3.68	65	15	1.62	0.02	300	4,500
Site 9,15	Main	7.36	100	10	0.72	0.01	350	3,500
13	3	152.06	300	207	1.15	0.24	700	144,900
Site 42	3	7.36	100	36	0.72	0.03	350	12,600
TOTAL				**3,612**				**1,429,650**

Table A.4.9 McMaster University District Heating System - Steam Substations

Site	Peak-kW		Substation $
36	617		36,555
35	617		36,555
27&28	1,235		52,610
3	617		36,555
19	617		36,555
24	617		36,555
38	617		36,555
29	617		36,555
5&23	1,235		52,610
1	617		36,555
8	617		36,555
2	617		36,555
11A	309		25,550
21	617		36,555
10A	309		25,550
39	617		36,555
17	617		36,555
20	617		36,555
10B	309		25,550
11B	309		25,550
22&32	1,235		52,610
9&15	1,235		52,610
42&25	1,235		52,610
40	617		36,555
18	617		36,555
26	617		36,555
6	617		36,555
4&30	1,235		52,610
37	11,112	Part steam supply	290,220
43	617		36,555
13	617		36,555
16	617		36,555
34	617		36,555
44	617		36,555
TOTAL	**33,952**		**1,548,837**

Table A.4.10 McMaster University District Heating System - Hot Water Substations

Site	Peak-kW	Comment	Substation $
36	617		36,555
35	617		36,555
27&28	1,235		52,610
3	617		36,555
19	617		36,555
24	617		36,555
38	617		36,555
29	617		36,555
5&23	1,235		52,610
1	617		36,555
8	617		36,555
2	617		36,555
11A	309		25,550
21	617		36,555
10A	309		25,550
39	617		36,555
17	617		36,555
20	617		36,555
10B	309		25,550
11B	309		25,550
22&32	1,235		52,610
9&15	1,235		52,610
42&25	1,235		52,610
40	617		36,555
18	617		36,555
26	617		36,555
6	617		36,555
4&30	1,235		52,610
37	10,374	incl. 1 MW boiler	390,220
43	617		36,555
13	617		36,555
16	617		36,555
34	617		36,555
44	617		36,555
TOTAL	**33,221**		**1,648,837**

Appendix 5

Current Status of High-Temperature Hot-Water Boiler Applications in Canada

Appendix 5

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Appendix 5

Current Status of High-Temperature Hot Water Boiler Applications in Canada

Overview

The objective of the work on which this Appendix is based was to contact the operators of sites with high-temperature hot-water systems to determine the following:

1) The origin of the project in terms of how and when the system was developed;

2) Current status of the project;

3) Summary of current operating successes and problems.

The information is presented as reported by the individuals interviewed and does not represent the opinion of the IEA Consulting Group.

Summary of Findings

The results of the interviews are summarized briefly below:

1) The operators were generally satisfied with the systems because they had fewer operating problems and lower heat losses than steam systems;

2) The systems were considered to have high efficiencies. However, it should be noted that few of the installations had any reliable means of measuring efficiency or heat losses in the distribution systems;

3) Many of the operating problems resulted from design problems because the systems were built as prototypes;

4) The systems were considered dangerous to operate because of the high temperatures and pressures involved;

5) The operators perceived that highly qualified staff were required to operate the systems. In fact, qualifications for high-temperature hot water and steam systems should be similar;

6) Some systems had leakage problems while other systems worked well. The design of high-temperature systems (both hot water and steam) is more complex than for low temperature systems, especially for directly-buried applications. Well designed and properly maintained systems can work well while minor design errors can create problems that are costly to correct.

Canmet Complex, Ottawa, Ontario

Contacts: Michel Ladouceur
Head, Building Heat Distribution: 613-993-7058

Gordon Birks
Chief Central Heating Plant : 613-993-2719

Chronology

- System installed in 1967 as an experimental pilot plant (generator vessel) for general heating purpose.
- Reasons for high temperature hot water choice:
  * Capital cost economy: lower initial cost due to smaller piping size relative to steam.
  * Type of buildings to be heated i.e. large open areas (labs) heated by radiant panels.

Type of System

- High temperature hot water: 350°F, 150 psi.
- Original plan: Buried piping with poured insulation and cathodic protection. System replaced in 1986 with a tunnel system because high corrosion was experienced with buried system.
- System connected to a group of 11 buildings (in line over a half mile distance). Each building has 3 sections: offices, labs and research facilities. Eight out of 11 buildings have radiant panels. Each building has a heat exchanger.
- Connection to heat exchangers through pneumatic valves to control output water within 160° to 180°F range.
- Closed loop system with chemical products added to prevent piping, valve and gasket oxidation.
- Major changes foreseen for summer 1988: addition of 5 ventilation systems and 5 new heat exchangers.

Participants

- At time of installation: unknown.
- Current operation:

* Split into 2 groups.

* One group involved with the central heat plant, production of hot water and distribution to the buildings.

* One group involved with the distribution of hot water in the buildings.

Current Status

- Appraisal from chief of central heat plant:

  * Very positive, high energy efficiency, does not see major disadvantages.

  * High temperature hot water is seen as generating fewer problems than steam, is steadier, more energy efficient when proper chemical treatment is used, and is easier to handle.

  * System components are smaller than steam systems components and as such are easier to maintain and have lower failure rates. However, operating personnel has to be highly qualified.

- Appraisal from chief of building heat distribution:

  * Excellent system to heat buildings: provides energy conservation, can be merged to include heat transfer systems for a better control of buildings temperatures.

  * Flexible enough to be merged with radiant panels.

  * Requires low maintenance.

- Problems:

  * High temperature hot water is a very dangerous product to operate since it is operated at much higher pressure than steam. If some leakage occurs in the multiple valves and control elements, very serious injuries may occur. However, no accidents have occurred at the Canmet complex.

  * High maintenance is required, especially during the summer.

  * Booster pumps previously installed in the buildings were removed in 1982 with the objective of conserving energy. This had the effect of

decreasing the amount of input hot water necessary to feed the heat exchangers during the coldest periods of winter. Problem will be resolved in the summer of 1988 by adding a variable speed drive pump.

Memorial University, St. John's, Newfoundland

Contact: Hayden Kirnan,
Associate Director of University Works:709-737-8725

Chronology

- System installed in 1973 (engineering consultants: Granek and Associates, Toronto). Many buildings added to original installation since then.

- Reasons for high temperature hot water choice (assumed by respondent):

  * Lower initial capital cost than for steam.

  * The very long distance covered by the distribution system (i.e. optimizing heat losses over a long distance).

  * University decision makers followed the consultant's advice in choosing such a system.

Type of System

- High temperature hot water system: 354^{o}F
  2 boilers of 60 million Btu/hr each
  1 boiler of 40 million Btu/hr

- Oversized by 100% in capacity for further building additions.

- Distribution system installed in a 3000 foot long underground tunnel. System feeds 2 central heat transfer locations plus some buildings with heat exchangers.

Participants

- At time of installation: unknown.

- Current operation and maintenance: 17 persons including a chief mechanical engineer.

Current Status:

- Very pleased and extremely satisfied with the system.

- No major problems met in the system's operations - no leakages.
- Minor problems with tubes burning in the boilers-

considered normal tube wear and replacement.

- Use Dearborn Chemical products.

- Critical issue is the necessity for continuous and proper maintenance of piping and peripheral systems with highly qualified operation staff.

CFB Gagetwon, New Brunswick

Contact: Burny Wile
Head Central Heating Plant: 506-422-2000
ext. 2345

Chronology

- System commissionned by Department of National Defence (D.N.D.) in 1954 as a pilot plant. D.N.D. encouraged the construction of a coal burning unit. The project was put in operation in 1956.

- Reasons for high temperature hot water choice:

  * Lower initial capital cost (than steam).

  * Confidence in the results from European experience.

- Major changes since original installation:

  * late 1960: Change of fuel supply from high-sulphur coal to low-sulphur coal because of contamination problems in preheaters and premature metal failures due to the high level of sulphur in the coal used.

  * 1975 : All boilers were retubed due to high corrosion associated with high sulphur coal (the damage was already done before the type of coal was changed in 1960).

  * 1974 : All original expansion joints were replaced because continuous leakages were leading to external corrosion.

Type of System

- High temperature hot water: 370°F, 160 psi main boiler, 265 psi pump pressure.

- Original plan: 7 miles of piping in a tunnel, 2.5 miles of piping buried in a static inverted trench (S.I.P.). Some lateral lines buried with oured insulation (Ricwil system).

- Most lines with Ricwil system are currently being replaced (80% as of summer 1988) with an S.I.P. because of:

  * Extensive corrosion in the Ricwil system and resulting

failures due to contact with wet soil.

* Frost breaks at the buildings causing fractures in the distribution system

- Three boilers of 70 million Btu/hr each (max pump capacity: 1500 gallons/min). Effective capacity in operation: 150 million Btu/hr.

- Chemical treatment: Oxygen scavenger and water softener.

Current Status

- Overall efficiency rated at 80%.

- Problems with the high-temperature hot-water systems:

  * Many different lines with many types of expansion joints lead to enormous maintenance problems.

  * Many different racks and anchors make system complex.

  * The system is old and was inadequately designed because it was conceived as a prototype by misinformed designers (at that time).

  * Failure of expansion joints: design problem solved by replacing the joints at high capital cost.

  * Separation of racks/anchors from back wall in the concrete tunnel: problem occuring as a consequence of joint failures and is solved by replacing anchors and racks.

  * Use of coal as a primary fuel causes continuous problems.

- Advantages of high-temperature hot-water:

  * Energy conservation due to reduced heat losses (compared to steam).

  * High thermal inertia of high-temperature hot-water (relative to steam) allows the use of residue heat in hot water as a thermal sink when a shut down is required and keeps lines from freezing.

CFB Shannon Park, Nova Scotia

Contact: Tom Hearnst
Chief Central Heat Plant: 902-998-7747

Chronology

- System installed in 1952 to supply space heat and domestic hot water to 91 buildings of which 81 are 6 to 8 unit apartment buildings.

- Reasons for high-temperature hot-water choice:

  * Distance: lower heat losses were expected in 9000 foot tunnel (compared to steam).

  * Safety: steam would have been dangerous to use for apartment buildings.

  * Dual supply: space heat and domestic hot water.

Type of System

- High-temperature hot-water: 363°F, 120 psi

- Supplies 91 buildings (81 apartment buildings plus shops, office buildings, etc). Each building is equipped with 8-10-15 psi pumps and pressure reducing valves.

- One main tunnel plus lateral lines to buildings.

- Three horizontal tube boilers (Dominion Bridge), 300 hp each, 1 million Btu/hr. Original fuel was coal, converted to oil in the early 1970's to decrease maintenance costs.

- Chemical products: SO_3, caustic soda.

Current Status

- Very high efficiency of the distribution system: 1% or less water make up.

- Very inefficient boilers (aging boilers with 600% excess air): some modifications planned for summer 1988.

- The heat plant is shut down during the summer for major maintenance work.

- Daily inspection rounds are carried out from Monday to

Friday.

- No major problems encountered due to excellent and very qualified maintenance and operating crew. Each staff member is a certified Stationary Engineer.

- Shortly after the start of operations, the original bronze/brass pumps were replaced with stainless steel pumps and fittings due to corrosion.

- Advantage of high-temperature hot-water:

  * Eliminates extra cost of chemical treatment (relative to steam).

  * Eliminates need for steam traps, flash tanks, etc.

- Problems with high-temperature hot-water:

  * Dangerous product to handle when piping or equipment bursts.

Mirabel Airport, Quebec

Contact: Marc Jubinville
Chief, Central Heating Plant: 514-476-3130

Chronology

- System installed in 1974, operational in 1975 (Brais Frigon and Assoc.: engineering consultants).
- Reasons for high-temperature hot-water choice:
  * Similar to the system at Dorval Airport, Montreal.
  * Provided for uniform management and maintenance practice, even though both systems are managed independently.

Type of System

- High-temperature hot-water: 400°F, 250-300 psi.
- Distribution system: buried piping (Ricwil system) plus cathodic protection and various accesses to main piping.
- 7000 feet long, feeding various buildings and the airport terminal.
- 1500 gallon/min. flow with an emergency supply and return line (considered as essential).
- Major changes since installation:
  * Addition of two electric boilers (2000 kW) for higher bargaining power with energy suppliers.
  * Replacement of 3 air conditioning systems (800 tons each) with 2 centrifugal systems (800 tons each) and 1 absorption type system.
  * Installation of heat recuperators in stacks (1983-1984) plus other energy conservation measures.

Current Status

- Gas boiler efficiency: 80%.
- Distribution system efficiency: 3%-5% heat losses.
- Personnel: 2 operators per shift (16 person years). The heat plant and air conditioning systems are

The heat plant and air conditioning systems are computerized.

- Advantages of high-temperature hot-water:

  * Low water make up and significantly lower chemical treatment result in cost savings.

  * Large thermal inertia of hot water (compared to steam) allows system to supply heat during temporary shut-downs.

  * Reduced heat losses over the long pipe network due to system design.

  * Independence of motor energy from thermal energy provided by high-temperature hot-water. With a steam system, heat losses have to be compensated for by increasing the pressure at the heat plant.

- Problems with high-temperature hot-water:

  * No major disadvantages if highly qualified personnel are used to operate and maintain the system.

  * A hot water system is more dangerous to operate than a steam system because of the high pressure.

  * Requires more monitoring and maintenance than steam.

  * Ricwil system is difficult to maintain. A walkthrough tunnel would be preferred.

  * The chief of the central heat plant has to have control of the operation and maintenance of the entire line of distribution including the peripheral equipment in the buildings. For example, a pressure drop at a heat exchanger caused by an unqualified plumber could cause serious problems at the heat plant for which the plant supervisor would be considered responsible.

Dorval Airport, Montreal, Quebec

Contact: Ronald Doyon
Chief Central Heating Plant: 514-633-2894

Chronology

- System installed in 1959 with a capacity double the actual need. (Engineering consultants: Wiggs, Lindsay and Assoc.). Design characteristics copied from a plant operated in Germany.

- Reason for high-temperature hot-water choice: high stacks, smoke and humidity usually caused by steam system could be avoided. Navigational problems for aircraft were therefore reduced.

Type of System

- High temperature hot water: 400°F (return 300°F), 250 psi at central plant (may go up to 300 psi).

- Capacity: 220 million Btu/hr can be increased to 350-400 Btu/hr (now operates at 75% capacity).

- Boilers fueled by natural gas. Converted from #6 oil after installation. Two boilers of 70 million Btu/hr and 2 boilers of 40 million Btu/hr each. Water inlet temperature: 260°F. Flue gas temperature: 375°F

- Heat plant and distribution system are automated.

- Annual budget: $1.8 million ($1.2 million in fuel plus operating budget).

- Distribution system installed in a tunnel: 3500 feet to main terminal and peripheral buildings and 1280 feet to 7 hangars. Water flow: 480,000 pounds/hr.

- Major changes since installation:

  * Conversion from #6 oil to natural gas.

  * For energy savings, operators keep tunnel ambiant temperature at 110°F by shutting off ventilators.

  * Now operated 7 months per year as opposed to 365 days/year at the beginning of operation.

  * Three electric boilers for DHW were added since 1985 to allow shut down of central plant during the

summer (May 1-Sept. 30). Air conditioning is provided by an independent system.

* Renovations from 1981-1985 for minor repairs and energy conservation.

- Problems:

  * 1975: Major shut down of central heat plant because a one inch pipe burst and had to be repaired.

  * 1980: Boiler insulation replaced as a preventive maintenance measure.

  * 1985: Corrosion in boilers on external tubes (gas side) resulted in annual replacement of tubes since 1985. Boilers planned to be replaced one per year starting in 1990 (boilers are almost 30 years old).

Current Status

- Central plant efficiency: 85%.

- Heat losses: 4% at the output point. Temperature drops from 400°F at the plant to 396°F at the far end of the system.

- Very satisfied with the current efficiency.

- 2 teams of operators: 1 team at central plant, 1 team for building peripheral systems. Both are controlled by the plant supervisor.

- Advantages of high-temperature hot-water:

  * Very low heat losses over long distances.

  * Potential to detect instantaneously any incident at the user's end of the system.

  * Significantly lower corrosion and water intake than for steam and therefore, significantly lower costs for water treatment.

- Problems with high-temperature hot-water:

  * Very dangerous product to handle.

  * Need highly qualified and properly trained operating and maintenance personnel.

* Need on-site stock of heavy-duty parts and components.

* In remote regions, operators of high-temperature hot-water systems may be at a disadvantage if delays occur in receiving parts.

* Difficult to detect minor leaks.

* Need more sophisticated (and more costly) control instruments for high-temperature hot-water systems.

* Need heavy-duty components and equipment connected to main distribution lines.

* According to the respondent, there is lack of good "PRACTICAL" training programs for the operation and maintenance staff of high-temperature hot-water systems.